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CONTENTS

[The letters in parentheses preceding the titles designate separately published chapters]

ILLUSTRATIONS

[Plates 1, 2, and 7-11 are in pocket]

Geology of the Alvord Mountain Quadrangle San Bernardino County California

By F. M. BYERS, JR.

GEOLOGIC INVESTIGATIONS OF SOUTHERN CALIFORNIA DESERTS

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Part of a general appraisal of the mineral resources of the Mojave Desert region

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CONTENTS

ILLUSTRATIONS

[Plates 1 and 2 in pocket]

TABLES

GEOLOGIC INVESTIGATIONS OF SOUTHERN CALIFORNIA DESERTS

GEOLOGY OF THE ALVORD MOUNTAIN QUADRANGLE, SAN BERNARDINO COUNTY, CALIFORNIA

By F. M. Byers, Jr.

ABSTRACT

The rocks of the Alvord Mountain quadrangle in the central Mojave Desert of southern California, consist of a pre-Tertiary basement complex of metamorphic and igneous rocks overlain by nonmarine sedimentary and volcanic rocks of Tertiary and Quaternary age. The pre-Tertiary rocks, which include rocks of probable Precambrian age, consist of schists, gneisses, migmatite, and carbonate rocks, invaded by late Mesozoic plutonic rocks related to the Southern California and Sierra Nevada batholiths. Rocks of uncertain age include dikes of granodiorite porphyry and rhyolite, which are probably late Mesozoic or early Tertiary in age, and arkosic conglomerate, which may be as old as late Paleozoic or as young as early Tertiary.

The known Tertiary system of layered rocks, as exposed on the northern and eastern flanks of Alvord Mountain, ranges in thickness from 0 to 2,250 feet and lies unconformably on an irregular erosional surface carved on the pre-Tertiary basement complex. Marked changes in thickness and lithology are typical of most units. The lower 1,000 feet of the Tertiary system at its maximum exposed thickness consists of three newly named formations in ascending order: the Clews fanglomerate, the Alvord Peak basalt, and the Spanish Canyon formation, which consists of tuff, arkosic sandstone, and olivine basalt. These formations are probably early to middle Miocene in age. The upper 1,250 feet of the Tertiary system at its maximum exposed thickness consists of the Barstow formation of middle and late Miocene age. The lower member of the Barstow formation is composed mainly of arkosic sandstone and averages about 900 feet in thickness over much of its exposed extent. *Merychippus tehachapiensis*, a middle Miocene horse, has been found 400 to 500 feet above the base. The middle tuffaceous member, composed of sandstone and tuff and about 5 feet thick, also contains middle Miocene vertebrate remains. Near its base the upper member is composed largely of arkosic sandstone; locally it grades stratigraphically upward into granitic fanglomerate.

Dissected granitic fanglomerate of Pliocene and possibly Pleistocene age is as much as 1,000 feet in thickness. Other rocks of late Tertiary and early Quaternary age include the volcanic rocks of Lane Mountain (late Pliocene(?) age) in the northwesternmost part of the quadrangle, olivine basalt, volcanic gravel, and breccia and fanglomerate. The Quaternary rocks consist of basalt flows, landslide and talus deposits, Manix lake beds, older windblown sand, and terrace deposits and recent alluvium, windblown sand, and the clay and silt of present playas.

Attitudes in the foliation of the pre-Tertiary metamorphic rocks have a trend slightly west of north similar to that of fold axes in the northern part of the quadrangle. In the southwestern part of Alvord Mountain, the foliation attitudes suggest an anticline plunging northwest. The larger bodies of intrusive rock are concordant to the foliation of the metamorphic rocks.

Movements along major east-trending faults parallel to the Garlock fault 25 miles north dominated the tectonics in the Alvord Mountain quadrangle during Cenozoic time. The Bicycle Lake fault zone, in the northernmost part of the quadrangle, may have had a considerable left lateral component of movement during late Cenozoic time. The Coyote Lake fault, largely under alluvium, enters the Alvord Mountain quadrangle 3 miles north of Coyote Lake. It may extend eastward across the middle of the quadrangle into the Cave Mountain quadrangle; its vertical movement north of Coyote Lake was apparently up on the north side, whereas in the eastern part of the Alvord Mountain quadrangle the movement probably was up on the south side.

Alvord Mountain is a broad upwarp of the pre-Tertiary crystalline rocks whose elevation was probably accompanied by some vertical uplift along a marginal fault at the south front of the range. The Tertiary layered rocks on the eastern flank of Alvord Mountain are arched into a broad anticline that plunges eastward from the pre-Tertiary granitic and metamorphic rocks. The Alvord Mountain upwarp is further complicated in the area underlain by Tertiary rocks by the subsidiary Spanish Canyon anticline, whose axis curves from north to west, and by many minor faults, the largest of which are northeast-trending normal faults that dip southeast. The southeasternmost part of the Alvord Mountain upwarp is broken by two east- to northeast-trending fault zones, which may merge westward under alluvium to form the southern boundary fault of the Alvord Mountain upwarp.

A former surface, partly erosional and partly depositional, on volcanic gravel is now being dissected in the southeastern part of the quadrangle. This surface probably extended to the northwestern part of the quadrangle in early Quaternary time, prior to renewal of the warping and faulting that produced the present arrangement of mountains and playa basins. The Alvord Mountain upwarp and other areas of pre-Tertiary crystalline rocks have been maturely dissected. Small stream washes are well adjusted to the structure of the Tertiary layered rocks, but a few larger washes appear to be locally antecedent or superimposed.

The mineral resources of the quadrangle are chiefly gold and limestone. The tungsten mineral scheelite was found in 1953 in a tactite deposit in the northwestern part of Alvord Mountain. The lower part of the former basin of Miocene age in which saline deposits may have accumulated was east or south of the quadrangle.

INTRODUCTION

LOCATION, ACCESSIBILITY, AND SETTLEMENTS

The Alvord Mountain 15-minute quadrangle is in the central Mojave Desert region of California. The southeast corner of the quadrangle is at latitude 35° N. and longitude 116° 30′ W., about 30 miles N. 75° E. of Barstow, Calif. (fig. 1). The area is easily reached from Barstow via U.S. Highway 91–466, which passes through the southeast corner of the quadrangle (pl. 1). As the map shows, most of the north half of the quadrangle is within the boundaries of the Camp Irwin Military Reservation, and the highway from the camp headquarters to Barstow cuts across the northwest corner of the

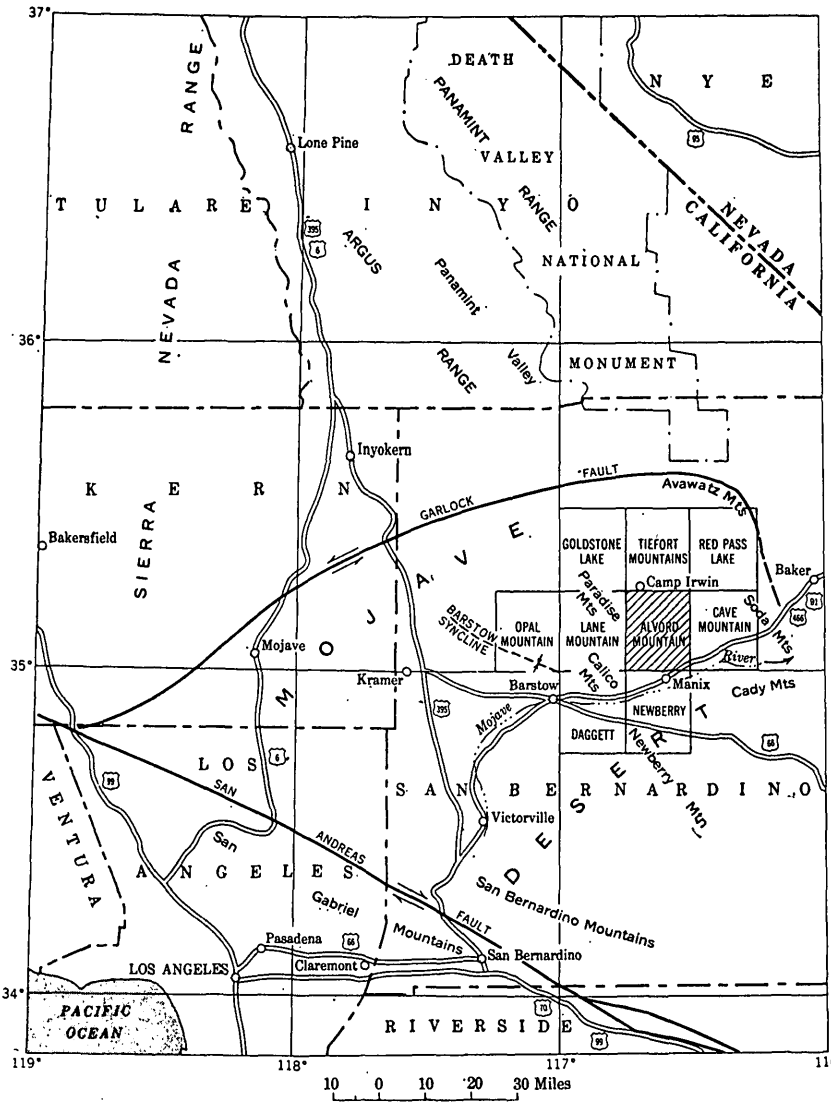


FIGURE 1.—Index map of Mojave Desert region, California, showing location of Alvord Mountain quadrangle and other quadrangles mentioned in text. (Faults after Hill and Dibblee, 1953, pl. 1).

quadrangle. These highways, together with the unimproved dirt roads that traverse the quadrangle, make all parts accessible, especially in vehicles suitable for off-road travel. Except for a watchman at the Alvord mine and a few railroad employees at Field, a siding on the Union Pacific Railroad, there are no permanent residents within the quadrangle. The Camp Irwin headquarters is 0.9 mile above the north boundary, and Manix, a small community on U.S. Highway 91–466, is 2.2 miles below the south boundary.

PURPOSE AND SCOPE OF REPORT

The geology of the Mojave Desert region was described in a general way by Thompson (1929, p. 98–116, pl. 8) in his report on the groundwater resources of the region. The geology of parts of the Alvord Mountain quadrangle was mentioned by Buwalda (1914, p. 445–446) and by Thompson (1929, p. 261, 537), but no detailed geologic mapping had been done prior to the present investigation, partly because of lack of adequate base maps.

The fieldwork upon which this report is based was undertaken as part of a general appraisal of the mineral resources of the Mojave Desert region. Saline deposits, principally borates, are known to occur in Tertiary beds or layers equivalent in age to those exposed in the Alvord Mountain quadrangle. Though no saline deposits crop out in the quadrangle, mapping of the Tertiary beds was undertaken as part of the studies of ancient drainage lines in order to predict where possible buried Tertiary lake basins might be found.

The pre-Tertiary geology was mapped in reconnaissance to learn about possible source areas of pebbles in the Tertiary beds. No attempt was made to solve detailed stratigraphic and structural problems of the pre-Tertiary rocks. Such studies were made in the adjoining Lane Mountain quadrangle (fig. 1) by McCulloh (written communication, 1955).

FIELDWORK AND ACKNOWLEDGMENTS

Most of the fieldwork for this report was done during the first 6 months of 1953. Cliffton H. Gray, Jr., assisted in mapping during April 1953. Information provided by Thane H. McCulloh, who mapped the adjacent Lane Mountain quadrangle to the west, was used freely. Further acknowledgments are given in the text whenever his information is used.

D. F. Hewett and several other members of the Geological Survey visited the area at different times and made helpful suggestions during the course of the work. Robert D. Allen, mineralogist, determined percentages, and identified many, of the minerals in the plutonic rocks. The writer is indebted to Mr. Francis G. Dell'Osso, president of the Dell'Osso Gold Mining Co. for his hospitality at the Alvord mine. Military personnel at Camp Irwin provided a base of operations for fieldwork during the mapping of the northern part of the quadrangle.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Alvord Mountain quadrangle contains low dissected mountains or hills of indefinite trend that are typical of the central Mojave Desert region. The area that is shown as Alvord Mountain on plate

1 was called Alvord Mountains by Buwalda (1914, p. 445), Thompson (1929, p. 537), and other geologists who have worked in the Mojave Desert region. The name Alvord Peak is used in this report to designate the highest promontory of Alvord Mountain, which has an altitude of 3,456 feet in the SW 1/4 sec. 25, T. 12 N., R. 3 E. (pl. 1). Clews Ridge, a prominent feature in the southeastern part of Alvord Mountain, is herein named for Joe Clews, a partner of Charles Alvord after whom Alvord Mountain was named (Weight, 1950, p. 5).

The maximum relief of the Alvord Mountain area is about 1,000 feet, but in most localities the relief is less than 500 feet. The western part is an area of rugged hills that rise from an altitude of about 2,000 feet at the head of the alluvial apron on the south to culminate in Alvord Peak, in the central part of the mountain. The eastern part is an area of lower altitude and relief and comprises colorful badlands separated by resistant hogback ridges. Four southward-draining dry washes transect these badlands and ridges. The westernmost wash has been called Spanish Canyon after the Old Spanish Trail between San Bernardino and Salt Lake City (Weight, 1950, p. 5–6) and is so designated in this report. A prominent asymmetric ridge fringes Alvord Mountain on its northeast flank. This ridge consists of a steep cliff 200 feet high facing the lower badland area, and a long gentle slope to the north and east; it becomes less distinct westward around the northwest flank of Alvord Mountain and merges with low dissected hills north of Coyote Lake (pl. 1).

In the northern part of the quadrangle a group of hills of a few hundred feet relief lie just north and northeast of Langford Well Lake. Low, isolated hills form the landscape in the northwest quarter. Of especial interest is a rounded topographic swell (pl. 1) in secs. 25, 26, 35, and 36, T. 13 N., R. 2 E., about 2 miles southeast of the Barstow-Camp Irwin road, called the Noble Dome, after Levi F. Noble, by Davis (1933, figs. 6 and 20).

The lowland areas are parts of enclosed topographic basins; only Langford Well Lake basin is entirely within the quadrangle. The playa surface of Coyote Lake basin, of which the eastern part lies within the quadrangle, is at an altitude of 1,707 feet. The broad alluvial slopes in the northeast part of the quadrangle drain eastward for about 10 miles beyond the eastern border of the quadrangle to West Cronese Lake, a playa in the Cave Mountain quadrangle. The alluvial slope south of Alvord Mountain drains into the Mojave River, which is a few miles south of the southern border of the quadrangle, and eventually into Soda Lake, 25 miles eastward.

CLIMATE AND VEGETATION

The climate of the Alvord Mountain quadrangle is arid. The vegetation is mainly creosote brush, sagebrush, and several small varieties of cactus. Small willow trees and, locally, vines bearing small gourds are found in the principal washes that cut through Alvord Mountain.

WELLS AND SPRINGS

The watering places in the Alvord Mountain quadrangle were first described by Thompson (1929, p. 259–263, 279–285). The wells in the area include the Alvord well, the Langford well, which was dry in 1953, and several wells south of Coyote Lake (pl. 1). In 1953 the water levels in a few of the wells south of Coyote Lake were 30 to 40 feet below the top of the casing. Both Mule Spring, about 1 mile north of Alvord well, and Garlic Spring, about 2 miles north of Langford well, have a small discharge of weakly saline water that can be drunk in an emergency. Jack Rabbit Spring on the north side of Coyote Lake was not visited, but judging from its nearness to this dry lake, the spring is probably highly saline or dry during the summer. Water analyses from the Alvord well and the two springs are presented in table 1.

TABLE 1.—*Chemical analyses of water samples from SE¼ sec. 11, T. 11 N., R. 3 E., Alvord Mountain quadrangle*

[Henry Kramer, analyst]

Analytical factor	Well or spring (date sample collected)		
	Alvord well (May 30, 1953)	Mule Spring (Oct. 10, 1954)	Garlic Spring (June 1, 1953)
Constituents, in parts per million:			
Ca	4	4.8	24
Mg	0	.2	2
Na	385	492	169
K	12	9.5	8
Li		Trace	
Sr		.32	
CO_3	59	119	0
HCO_3	439	320	256
Cl	198	242	62
SO_4	112	282	138
F	6.4	5.0	5.0
NO_3	2.0	8.4	.8
B	2.7	3.35	1.7
SiO_2	10	21.0	22.2
Electrical conductivity [1]	1,620	2,300	975
pH	9.1	9.30	7.75

[1] Equal to approximately 0.7 of the total dissolved solids.

GEOLOGY

On the basis of a profound unconformity, most of the rocks of the Alvord Mountain quadrangle are divided into pre-Tertiary basement rocks and Tertiary and younger rocks. A few dikes and other rock masses, however, which occur in isolated exposures cannot be placed definitely in either of these two categories. The pre-Tertiary rocks of the basement complex crop out chiefly in the northern half of the quadrangle and consist of schists, gneisses, and carbonate rocks intruded by plutonic rocks, including quartz monzonite, grandiorite, and diorite of late Mesozoic age. The Tertiary and Quaternary rocks of Alvord Mountain consist of a maximum thickness of about 2,250 feet of Miocene sedimentary and volcanic rocks overlain by granitic fanglomerate and volcanic gravel of late Tertiary and early Quaternary age. In the northern part of the quadrangle, only late Tertiary and early Quaternary volcanic rocks, including breccia and fanglomerate, and granitic fanglomerate rest on the pre-Tertiary basement rocks. Quaternary deposits include basalt flows, landslide and talus deposits, Manix lake beds, older windblown sand, terrace deposits on bedrock, alluvium, windblown sand, and the clay and silt of present playas.

Major faults are the principal structural features in the Alvord Mountain quadrangle; broad upwarps are also present in the pre-Tertiary rocks of the basement complex but are less easily recognized. Alvord Mountain itself is probably the result of an upwarping that occurred mostly in late Tertiary or early Quaternary time. Just east of Spanish Canyon the Tertiary layered rocks on the east flank of the Alvord Mountain upwarp have been arched into a prominent north-trending fold, which is herein named the Spanish Canyon anticline.

PRE-TERTIARY ROCKS

METAMORPHIC ROCKS AND MIGMATITE

The oldest rocks in the quadrangle are gneisses, schists, and carbonate rocks. In places they grade into migmatite containing igneous-appearing alaskitic, granitic, or dioritic layers that occur as lit-par-lit bands and less commonly as cross-cutting dikes. The metamorphic rocks are well exposed in the low hills north and northwest of Langford Well Lake and in the southwestern part of Alvord Mountain. Isolated masses crop out as scattered pendants within the large mass of plutonic rock in the northwest quarter of the quadrangle. There are also small exposures in sec. 12, T. 11 N., R. 4 E., at the east border of the quadrangle.

The metamorphic rocks form much of the dissected rugged terrain of the Alvord Mountain quadrangle. Tiefort Mountain, a few miles north, is composed largely of migmatite and rises 3,000 feet above the surrounding basins.

The most abundant metamorphic rock is well-foliated quartz-feldspar gneiss. Most of the gneiss contains about 5 percent biotite; muscovite gneiss is less common. Study of thin sections reveals a related variation in the light minerals: The biotite gneiss contains light-colored layers that are about 50 percent quartz, 25 percent orthoclase, and 25 percent oligoclase, whereas the muscovite gneiss contains less quartz and about 70 percent albite. Accessory apatite and sphene occur sparsely in both types of gneiss. In many places, the biotite-quartz-feldspar gneiss grades into gneissoid diorite, which in turn grades into quartz diorite and, in a few places, into granodiorite. These gradations take place across distances ranging from 50 to several hundred feet.

Biotite schist and muscovite-quartz-feldspar schist are intercalated with the gneisses but were not studied in detail.

The only units within the metamorphic rock areas that are shown separately on the geologic map (pl. 1) are the larger bodies of carbonate rocks. Of these, one near the Alvord mine has a total thickness of about 500 feet but may include isoclinally folded beds. Of the mapped beds in the low hills northeast of Langford Well Lake, the greatest measured thickness is 200 feet. The carbonate rocks are coarsely crystalline metalimestone, subordinate metadolomite, and dolomitic limestone.[1] Masses of lime-silicate minerals, not mapped separately on plate 1, occur mainly within the carbonate bodies but also occur within schist.

The white alaskitic lit-par-lit layers of the migmatite are an unusual rock and deserve more study as possible examples of metasomatism. In the northern part of the quadrangle, these rocks, though they have the even-grained texture and the mineral composition of an alaskite granite, grade, in a short distance, first into tabular masses of lime-silicate rock, thence along the strike into thin beds of limestone. A good example of this gradational relation can be seen in sec. 11, T. 13 N., R. 3 E. (pl. 1). The light-colored minerals constitute 98 percent of the rock and consist of 40 percent quartz and 58 percent albite-oligocase with antiperthitic inclusions of potassium feldspar; the dark minerals consist of about 2 percent biotite, anhedral grains of opaque material, and garnet. The texture is a xenomorphic granular mosaic, with maximum grain size of 1 mm. One thin section showed an interstitial mosaic of quartz and orthoclase. It is tempting to speculate that the alaskitic rock is a metasomatic replacement of limestone, but more work would be needed to prove this hypothesis.

Granite pegmatite and diorite pegmatite dikes, as much as 3 feet in thickness, are intruded along the foliation of the schists and gneisses. The granite pegmatites also crosscut the foliation and are more siliceous than the schist and gneiss of the country rock. The granite pegmatite or granophyre is grayish orange-pink, and contains graphic intergrowths of varying proportions of quartz and ortho-

[1] Metamorphosed or recrystallized limestone is herein referred to as metalimestone or crystalline limestone, following the usage suggested by Brooks (1954, p. 755).

clase.[2] The diorite pegmatite is unusual in its high proportion of hornblende, much of it in crystals 2 inches long. A chemical analysis of hornblende was published by Allen and Kramer (1955, p. 528). The major constituents of a typical diorite pegmatite are andesine (60 percent) and hornblende (35 percent). The accessory minerals are biotite (2 percent), sphene (1 percent), quartz (1 percent), apatite (0.5 percent), and calcite (0.5 percent). The diorite pegmatite dikes are of about the same composition as the diorite gneiss in which they occur and are almost always parallel to the foliation.

The metamorphic rocks are moderately to highly metamorphosed, are largely sedimentary, and are mostly within the epidote-amphibolite metamorphic facies. Some of the rocks, however, are so thoroughly altered by metasomatic replacement that the original rock can no longer be recognized. The metalimestone intercalated parallel to the foliation of the gneisses and the high-quartz content of the gneisses indicate a sedimentary origin for the great bulk of the metamorphic rocks. McCulloh (1954; written communication, 1955) studied these ancient rocks in the adjacent Lane Mountain quadrangle to the west and presented much evidence for their sedimentary origin.

The gneisses, schists, and intercalated carbonate rocks are probably largely Precambrian, though they may include rocks as young as Paleozoic in age. No fossils were found. In the adjoining Lane Mountain quadrangle McCulloh (oral communication, 1953) found both Carboniferous and Triassic fossils in metalimestone intercalated with argillite, hornfels, and schist; these rocks antedate plutonic rocks continuous with those of the Alvord Mountain quadrangle. The fossil-bearing metasedimentary rocks in the Lane Mountain quadrangle, however, are not so highly metamorphosed as the schist, gneiss, and metalimestone in the Alvord Mountain quadrangle. McCulloh (1954, p. 18) suggested the possibility that many of the unfossiliferous schists and gneisses of the central and western Mojave desert may be early Paleozoic in age rather than Precambrian.

AMPHIBOLITE

In the northwestern part of the Alvord Mountain quadrangle (pl. 1), dark greenish-gray to greenish-black amphibolite occurs as small pipelike and tabular masses enclosed by diorite or quartz diorite. The pipelike or circular masses stand up in topographic relief along the highway from Barstow to Camp Irwin and in the northwestern part of sec. 12, T. 13 N., R. 2 E. Tabular masses of this rock crop out in secs. 31 and 32, T. 13 N., R. 3 E.; these are intruded by dikes

[2] Rock colors used in this report are those in the Rock-Color Chart distributed by the National Research Council (1948).

of moderate orange-pink granite pegmatite. The contact between the dioritic rocks and the amphibolite is commonly sharp, but neither rock sends apophyses into the other, so that age relationships could not be determined from field evidence.

The amphibolite is composed of 70 to 80 percent hornblende and 20 to 30 percent plagioclase (bytownite). The hornblende crystals are randomly oriented and are as much as 1½ inches in length; they contain poikilitically included small feldspar grains. Relicts of clinopyroxene, almost completely replaced by hornblende, were observed in one of the thin sections. The presence of clinopyroxene in association with bytownite suggests that the amphibolite is probably a uralitized pyroxenite. Rare pyrite and chalcopyrite crystals, less than 0.5 mm, are found in places. Similar rocks in the Lane Mountain quadrangle (fig. 1) that intrude Carboniferous rocks have been demostrated by McCulloh (1954, p. 20–21) to have formed early in the emplacement of the Mesozoic plutonic rocks.

PLUTONIC ROCKS

About one-half the exposures of the pre-Tertiary basement complex in the Alvord Mountain quadrangle are coarse-grained plutonic rocks that range from diorite to granite. These rocks are best exposed in the crystalline core of Alvord Mountain and in the northwestern part of the quadrangle, where they grade outward from quartz monzonite through mafic border facies into high-grade metamorphic rocks. In contrast to the metamorphic rocks, the plutonic rocks erode to low relief of rounded knolls. A light-colored, porphyritic quartz monzonite is shown separately on plate 1 by an overprint pattern; this rock mass constitutes the low rounded Noble Dome in secs. 23, 25, 26, and 36, T. 13 N., R. 2 E., and extends westward into the Lane Mountain quadrangle (fig. 1). Northwestward, the quartz monzonite grades into true granite in the Goldstone Lake quadrangle, where similar rock contains albite instead of oligoclase as the plagioclase feldspar (Ross C. Ellis, written communication, 1954). Darker quartz monzonite and granite that contain abundant mafic minerals occur in the crystalline core of Alvord Mountain (pl. 1); these darker plutonic rocks have formed a more rugged terrain than the light-colored rocks.

The quartz monzonite exposed on Noble Dome in the northwest part of the quadrangle has a composition approaching granodiorite in that the ratio of oligoclase to orthoclase exceeds 1:1 but does not quite equal 2:1. Around the edges of the dome, the quartz monzonite, by a slight increase in the ratio of plagioclase feldspar to potassium feldspar, grades into granodiorite, which is similar in appearance. Quartz in the quartz monzonite ranges from 25 to 35 percent and commonly occurs in aggregates whose grains have irregular sutured contacts and range in size from 0.1 to 2 mm. The quartz and feldspar grains are coarse and xenomorphic; they average about 5 mm, although calcic oligoclase phenocrysts in some phrases of the quartz monzonite are idiomorphic and reach a maximum size of 1 cm. Biotite, the chief mafic mineral, occurs as scattered flakes about 1 mm in diameter and constitutes 5 percent or less of the rock. Sparse hornblende, opaque oxides, and apatite are the accessories. The quartz monzonite and granodiorite in the northwestern part of the Alvord Mountain quadrangle are markedly light colored and are continuous with similar bodies to the west and northwest.

In contrast, the granite, quartz monzonite, and granodiorite in the core of Alvord Mountain contain less quartz and more mafic minerals than similar plutonic rocks northwest of Alvord Mountain. Granite, which was given a field identification of diorite, was found from a thin-section analysis to contain 20 percent quartz, 50 percent orthoclase, 20 percent oligoclase, and 10 percent mafic minerals, chiefly hornblende that imparts a dark appearance to the rock (Robert D. Allen, written communication, 1954). Specimens of quartz monzonite from Alvord Mountain all contain about 20 percent quartz, 8 to 16 percent biotite, a few percent hornblende, muscovite, and other accessory minerals; the remaining minerals are composed of roughly equal amounts of oligoclase and orthoclase. The granite and quartz monzonite in Alvord Mountain crop out in limited exposures that grade within a few inches or a few feet into very dark granodiorite, small masses of which seemingly occur as mafic inclusions in the lighter-colored rocks. In the field the granodiorites appear to be diorite and quartz diorite, but sufficient orthoclase is present to place these rocks in the granodiorite category, on the basis of orthoclase forming 10 to 33 percent of the total feldspar. Quartz content ranges from 10 to 15 percent; combined hornblende and biotite content ranges from 25 to 30 percent of the rock.

True diorities occur both in the northwestern part of the quadrangle and in the plutonic core of Alvord Mountain. A typical specimen of the diorite that encloses small amphibolite masses in sec. 12, near the Barstow-Camp Irwin highway, was found by Allen to contain quartz, 4 percent; andesine, 61 percent; hornblende, 27 percent; biotite, 6 percent; opaque oxides, less than 2 percent. A typical specimen of the dark mafic diorite that commonly appears as inclusions in quartz monzonite in the eastern part of Alvord Mountain contains 53 percent hornblende, 40 percent andesine, 3 percent biotite, and 4 percent accessories.

The percentage of mafic minerals is higher in the plutonic rocks of Alvord Mountain than in plutonic rocks exposed in the northwestern part of the quadrangle; this contrast in mafic minerals provides a basis for identifying the rocks, and hence their sources, among the debris in the Tertiary sedimentary rocks.

The age of the more mafic plutonic rocks exposed in the core of Alvord Mountain may not be the same as that of light-colored plutonic rocks exposed in the northwestern part of the Alvord Mountain quadrangle. The more mafic plutonic rocks, particularly the hornblende granite, resemble certain Precambrian granites in the eastern Mojave Desert region (D. F. Hewett, oral communication, 1954). Plutonic rocks of both Precambrian and late Mesozoic ages may be represented in the core of Alvord Mountain.

The age of the light-colored plutonic rocks in the northwestern part of the Alvord Mountain quadrangle and adjacent parts of the central and western Mojave Desert is probably about the same as that of the plutonic rocks of the Sierra Nevada range and of southern California. The time of emplacement of the various phases of plutonic rocks over an area as large as southern California or the Mojave Desert may have ranged from late Jurassic through most of Cretaceous. Larsen, (1948, p. 136), citing the works of Woodford and Harris (1938) and of earlier writers, first assigned an early Cretaceous age to the Southern California batholith; later he (1954, p. 25) assigned it a middle Cretaceous age on the basis of uranium-lead ratios. In the adjoining Lane Mountain quadrangle, fossiliferous rocks dated as Triassic occur in pendants or masses engulfed by the intrusive rocks (McCulloh, oral communication, 1954).

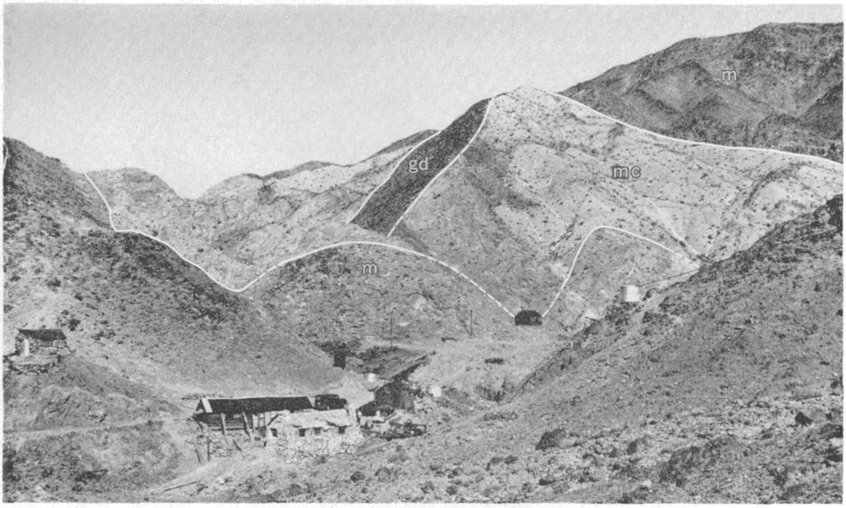
ROCKS OF UNCERTAIN AGE

DIKES

GRANODIORITE PORPHYRY

Granodiorite porphyry dikes, with dark dacite porphyry border zones several feet wide, strike slightly west of north across the foliation of the gneissic rocks in the southwestern part of Alvord Mountain. In the vicinity of the Alvord mine, two large dikes, each 150 feet wide, and many smaller ones cut the crystalline limestone at an oblique angle (pl. 3*A*). The dikes are nearly vertical or dip steeply eastward. They cut the plutonic rocks exposed in the crystalline core of Alvord Mountain. Flat-lying Alvord Peak basalt rests on the eroded ends of some dikes in the central part of the mountain.

The central part of a typical granodiorite porphyry dike has a seriate porphyritic texture and consists of about 40 percent phenocrysts (crystals greater than 0.5 mm). The phenocrysts are normally zoned oligoclase, biotite, and quartz. Oligoclase predominates and is commonly euhedral; some glomerophenocrysts are also present. The biotite phenocrysts are contorted and bent. Some quartz grains are euhedral; others are rounded and embayed with groundmass.

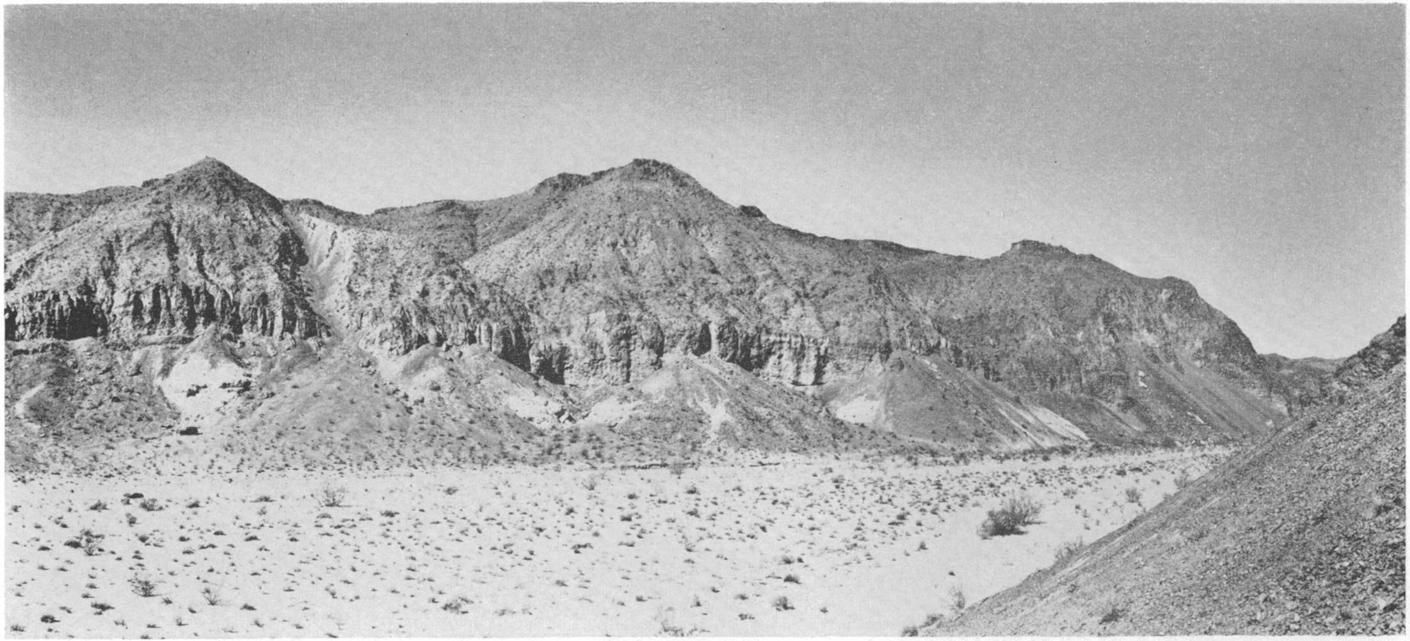


A. GRANODIORITE PORPHYRY DIKE

Dike (gd) cuts limestone (mc) 500 feet west of Alvord mine. Metamorphic rocks (m) form footwall and hanging wall on either side of the limestone.

B. GENTLY DIPPING FINE-GRAINED SEDIMENTARY ROCKS

At the base of the Clews fanglomerate (Tc) resting on uneven prefanglomerate surface of plutonic rocks (p). Looking toward east-central part of Alvord Mountain, SE¼ sec. 29, T. 12 N., R. 4 E.



FLAT-LYING FLOWS OF ALVORD PEAK BASALT

Flows conformably overlie the fine-grained uppermost tuffaceous part (about 70 feet exposed) of the Clews fanglomerate. West wall of Spanish Canyon along quarter-section line in N½ of sec. 6, T. 11 N., R. 4 E.

The accessory minerals occur as microphenocrysts that range in size from 0.1 to 0.5 mm; they include opaque oxide, apatite, muscovite and rare sphene. Aggregates of leucoxene(?), biotite, and opaque oxides pseudomorphic after sphene are also present. The groundmass is a finely crystalline xenomorphic aggregate of quartz and alkali feldspar and ranges in size from 0.02 to 0.04 mm. Because the groundmass is fine grained, intermediate in texture between the plutonic and the volcanic rocks of the area, the rock is classed as hypabyssal.

The dark border phase is more markedly porphyrytic, though phenocrysts seemingly make up a smaller percentage of the rock. The opaque oxides are more abundant and replace biotite. The groundmass is more finely crystalline (0.005 to 0.01 mm) and, like the more coarsely crystalline central part, consists of quartz and alkali feldspar intergrowths. The groundmass of this rock is so fine textured that it closely resembles a volcanic rock and hence merits the name dacite porphyry.

The age of the granodiorite porphyry dikes is in doubt. They are younger than the plutonic rocks of Alvord Mountain, which are of uncertain age. The dikes were emplaced prior to the deposition of the Alvord Peak basalt of Miocene age; they may be late Cretaceous or early Tertiary in age.

RHYOLITE

Two small rhyolite dikes, 10 to 50 feet thick, crop out in secs. 16 and 18, T. 13 N., R. 3 E., in the northwestern part of the quadrangle, (pl. 1); they are vertical and intrude gneiss. The rock is very light gray on fresh surface but weathers brownish yellow. Phenocrysts of clear feldspar and quartz, 0.5 to 2 mm in size, are scattered through the rock. As seen in thin section, the phenocrysts form less than 5 percent of the rock and consist almost entirely of sanidine and of rounded quartz that is embayed by the groundmass. Rare plagioclase phenocrysts are calcic oligoclase or sodic andesine. The groundmass is anisotropic with an average index of 1.515. These data are insufficient to classify the rock; hence the field name rhyolite is retained. The age of the rhyolite is unknown; it could be as old as Mesozoic or as young as late Tertiary. Both extremes are unlikely; more probably it was intruded into the gneiss during early or middle Tertiary time.

ARKOSIC CONGLOMERATE

Southeast of Coyote Lake in sec. 31, T. 11 N., R. 3 E., a well-indurated low hogback of dark-red arkosic conglomerate strikes about N. 40° W. and dips 65° NE. Three miles southeast along the strike and 2 miles south of the southern border of the quadrangle, red arkosic sandstone and conglomerate with similar attitude are well exposed in a roadcut of U.S. Highway 91–466. The arkosic conglomerate has the induration and toughness of quartzite and might so be called, were it not for the high content of feldspar fragments.

Younger beds overlie the arkosic conglomerate with marked angular unconformity. At the exposure in sec. 31, bedded volcanic gravel of Pliocene or Pleistocene age, possibly equivalent to a similar unit in the Lane Mountain quadrangle described by McCulloh (written communication, 1954), strikes N. 40° W., like the arkosic conglomerate, but dips 30° southwest, making an angular discordance of 85°. At the roadcut along highway 91–466, 2 miles south of the quadrangle, beds similar in lithology to the Barstow formation rest with angular unconformity on the arkosic conglomerate.

The dark-red arkosic conglomerate in sec. 31 has an exposed thickness of about 75 feet and contains sandstone interbeds 1 to 2 feet thick. Rounded to subrounded pebbles of purplish-gray lava and quartz monzonite are the chief constituents of the conglomerate. As seen in thin section, the fine-grained material in the conglomerate is very poorly sorted, and the grains are subangular. The estimated percentages of the various constituents are: Rock fragments, including plutonic and altered volcanic rock, 25 percent; feldspar, mostly oligoclase, 30 percent; quartz, 25 percent; interstitial hematitic cement, 15 percent; and accessory minerals, 5 percent. The accessories are biotite, opaque oxides, epidote, and sphene, in order of abundance.

Psilomelane veinlets as much as one-half inch thick cut the conglomerate. The arkosic sandstone near U.S. Highway 91–466 is better sorted and contains fine-grained interstitial quartz cement instead of hematite but otherwise is similar in mineral content to the arkosic conglomerate exposed in sec. 31.

The age of the arkosic conglomerate is not known, but two possibilities are considered. The presence of quartz monzonite fragments in the rock suggests that it postdates the late Mesozoic plutonic rocks. The high degree of induration and the marked angular discordance with Pliocene or Pleistocene sedimentary rocks indicate that the arkosic conglomerate is hardly younger than early Tertiary. As a second possibility, the arkosic conglomerate exposed in the Alvord Mountain quadrangle may be correlative with the Fairview Valley formation (Wright, and others, 1953, p. 167; Bowen, 1954, p. 68) 20 miles south of Barstow, Calif. Fossils in limestone pebbles and in the matrix of the Fairview Valley formation are Permian in age, and the formation is intruded by Triassic(?) metavolcanic rocks, according to T. W. Dibblee, Jr. (1956, written communication). Mc-

Culloh (1954, p. 17), in reviewing Bowen's evidence, believes that the Fairview Valley formation could be either Permian or Mesozoic.

TERTIARY ROCKS

The known Tertiary rocks of the Alvord Mountain quadrangle are grouped into four formations and are confined to Alvord Mountain and the immediate vicinity. The names of three formations are new and in ascending order are the Clews fanglomerate, which forms the base of the Tertiary stratigraphic sequence, the Alvord Peak basalt, and the Spanish Canyon formation, which consists of both volcanic and sedimentary rocks. These formations are all overlapped by the Barstow formation, a sequence of clastic sediments containing a middle and upper Miocene vertebrate fauna, in part similar to that of the Barstow formation in the Daggett and Opal Mountain quadrangles (fig. 1) farther to the west.

CLEWS FANGLOMERATE

The Clews fanglomerate is here named and defined after its type locality at Clews Ridge in the southeastern part of Alvord Mountain. The fanglomerate is the oldest Tertiary unit exposed on the flanks of Alvord Mountain; it rests on an uneven prefanglomerate surface of plutonic rocks (pl. 3*B*). Along the axis and flanks of the Spanish Canyon anticline, the formation is several hundred feet thick. Thicknesses and general descriptions of two measured sections, one on the west flank of the Spanish Canyon anticline and the other across Clews Ridge, are shown on plate 2. In the vicinity of Alvord Peak, the Clews fanglomerate wedges out westward between underlying plutonic rocks and the Alvord Peak basalt, which conformably overlies the fanglomerate. On the east flank of the Spanish Canyon anticline (pl. 1) and east of Clews Ridge, the Alvord Peak basalt is missing, and the Clews fanglomerate is overlain by the Spanish Canyon formation without recognizable discordance, though in places there appears to have been gullying at the top of the fanglomerate before deposition of the Spanish Canyon formation.

The Clews fanglomerate is divided for the purpose of the following stratigraphic description into three parts: a lower unit composed of fine-grained tuffaceous sediments, a middle unit of ridge-forming reddish-brown fanglomerate, which volumetrically constitutes about 90 percent of the formation, and an upper unit of sandstone with included tuff beds. The stratigraphic section at the type locality of Clews Ridge is given on plate 2.

The lower unit of the Clews fanglomerate is well exposed in the east half of sec. 29 (pl. 4). These beds are the finest clastic sedimentary rocks of Tertiary age exposed in the Alvord Mountain area;

they include a few thin beds of limestone. A measured section of these beds is given below:

Section of fine-grained lower unit of Clews fanglomerate north of fault in SE¼ sec. 29, T. 12 N., R. 4 E.

	Feet
Sandstone, arkosic, light reddish-brown at base; light-gray bentonitic interbeds near top	100
Limestone, brownish-gray	.2
Siltstone, bentonitic, light-gray; contains a few very thin limestone beds	50
Chert, vuggy, calcareous in middle of bed; northward grades into vuggy limestone	1
Siltstone, bentonitic, light-gray to very light gray; contains 1-in. bed of white chert 2 ft below top	40
Siltstone and claystone, bentonitic; alternating beds about 4 in. thick; mottled light-gray to purplish-gray	2
Sandstone, fine-grained, purplish-gray, thin-bedded (flagstone)	.5
Claystone, bentonitic, mottled-gray to purplish-gray	22
Granite breccia, blocks as much as 1 ft wide	3
Total measured section	218.7

Quartz monzonite basement.

The middle unit of the Clews fanglomerate consists of moderate reddish-brown fanglomerate with blocks of the local mafic plutonic rocks as much as 10 feet across (pl. 2). The thickness of this unit reaches a maximum of 500 feet but in places wedges out completely. Bedding is lacking, and in places the fanglomerate is sufficiently coarse and angular to be described as a sedimentary breccia. The massive fanglomerate sequence is interrupted in the lower middle by a 5- to 10-foot bed of sandy bentonitic tuff or bentonite (pl. 2), which makes a convenient marker bed. On the eastern side of Alvord Mountain where the Alvord Peak basalt is missing, the fanglomerate lithology of the middle part of the Clews fanglomerate persists to the upper contact with the Spanish Canyon formation (pl. 2).

Where the upper 200 feet of the Clews fanglomerate underlies the Alvord Peak basalt, it is markedly different from the rocks in the similar stratigraphic interval in areas where the Alvord Peak basalt is missing (pl. 2). In general, where the upper part of the Clews fanglomerate occurs beneath the basalt, it consists of yellowish-gray and moderate red sandstone, siltstone, white tuffaceous sandstone, and well-bedded pebbly sandstone, with pebbles of light-colored quartz monzonite porphyry and banded argillite from a source northwest of Alvord Mountain. The white tuffaceous sandstone is intercalated in the stratigraphic interval between 40 and 70 feet below the base of the Alvord Peak basalt. The white tuffaceous sandstone and sandy tuff beds form conspicuous white outcrops in the walls of Spanish Canyon. In less steep slopes, the tuffaceous beds are commonly covered by talus from the basalt (pl. 4).

The sandy tuffaceous beds in the upper part of the Clews fanglomerate closely resemble the much less extensive but thicker white tuffaceous beds at the base of the Spanish Canyon formation but are characterized chiefly by finer grain and more opaline silica and bentonite, which indicate greater alteration. A typical detailed section including the tuffaceous beds in the upper part of the Clews fanglomerate is given below.

Section of upper unit of Clews fanglomerate in SW¼ of sec. 30, T. 12 N., R. 4 E., on west side of Spanish Canyon

	Feet
Alvord Peak basalt.	
Clews fanglomerate:	
Sandstone, arkosic, moderate red, very coarse	40
Tuff, arkosic, light yellowish-gray, very coarse; conspicuous white rectangular feldspar grains, 2 to 4 mm long	13
Tuff, siliceous, light yellowish-gray; rounded pinkish-gray pumice fragments	.2
Tuff, bentonitic, pale-red to pale red-purple; friable, except where siliceous in lower 1 in.	.7
Tuff, arkosic, white; several thin bentonitic layers less than ½ in. thick	1.6
Bentonite, grayish-pink	.05
Tuff, arkosic, white; several thin bentonitic layers less than ½ in. thick	1.4
Tuff, siliceous, white, hard; sparse biotite flakes and sparse medium-grained arkosic sand	.1
Sandstone, arkosic, light yellowish-gray, medium-grained; grades downward to very coarse grained	20
Pebble conglomerate, arkosic, yellowish-gray	>100
Total measured section	>177

Several specimens of tuff beds that were examined in thin section consist mostly of recemented cellular anistropic groundmass of low index, about 1.50. Shards and angular fragments, 0.2 to 2 mm long, are clearly recognizable and are cemented by opaline silica. Broken crystals form 5 to 10 percent of the rock and are veined and embayed by the groundmass, largely opaline silica. The crystals are principally quartz, oligoclase, and potassium feldspar (sanidine?). Biotite is also present in the 0.1-foot-thick tuff bed of the measured section above. The crystals are well sorted with respect to size and range from 0.2 to 0.5 mm in length. Sparse lithic grains in one specimen are as much as 1 mm in diameter.

The Clews fanglomerate was derived from local source areas of the basement complex, which had an uneven topography. Biotite-rich quartz monzonite, aplite, and granite pegmatite blocks closely resemble those rocks now exposed in the crystalline core of Alvord Mountain. Along the east side of Spanish Canyon near the southeast corner, sec. 30, T. 12 N., R. 4 E., gently northward dipping

Clews fanglomerate rests on diorite cut by a 7-foot vein of white quartz. Angular fragments of this same white quartz are strewn through the basal 10 feet of the fanglomerate for several hundred feet north of the quartz vein. Mafic diorite blocks were not observed in the Clews fanglomerate; however, the diorite is less resistant than the more siliceous rocks and readily breaks down into a sand. For that reason it was probably not preserved in the Clews fanglomerate. The blocky, angular character of the debris is possibly due to local fault movements that brecciated the basement rock and prepared it for transport, for much of the coarser breccia is close to faults that apparently were active during deposition of the fanglomerate.

The one association of moderate reddish-brown fanglomerate with coarse angular debris of local derivation and the other association of yellowish-gray conglomerate with rounded pebbles that were derived from a considerable distance northwest of Alvord Mountain suggest that the reddish-brown coloration may be derived from local stripping of an old reddish-brown soil. In a few places in the outcrop of plutonic rock on the east side of Spanish Canyon, NE¼ sec. 6, T. 11 N., R. 4 E., for example, an old reddish-brown soil is still preserved on basement rock. The fact that the conglomerates containing well-rounded pebbles of distant origin are yellowish gray suggests that the red-weathered debris was washed free during transport.

The age of the Clews fanglomerate must be middle Miocene or older, because beds higher in the Tertiary stratigraphic sequence contain middle Miocene vertebrate fossils. The general conformable relationship between the Clews fanglomerate and higher beds indicates that it belongs in the same sequence as the overlying beds and probably is not much older than the fossiliferous beds. The Clews fanglomerate rests on a buried topographic relief of 1,000 feet carved on plutonic rock of probable late Mesozoic age; this deep dissection is commonly assumed to have taken place during latest Cretaceous and early Tertiary time, and it laid bare vast areas of late Mesozoic plutonic rock in the Mojave Desert region (D. F. Hewett, oral communication, 1954). The available evidence indicates that the Clews fanglomerate is middle Tertiary, possibly early or middle Miocene in age.

ALVORD PEAK BASALT

The Alvord Peak basalt, which caps the low domical summit of Alvord Mountain, is a nonporphyritic basalt flow sequence and is here named after Alvord Peak. At Alvord Peak the basalt is 300 to 400 feet thick and dips gently northwest to sec. 22, T. 12 N., R. 3 E. At the line between secs. 22 and 29, 8 or 9 basaltic flows are exposed in a steep-walled gorge 200 feet deep. The base of the formation is not exposed here. The Alvord Peak basalt is best exposed in the west wall of Spanish Canyon (pl. 4), sec. 6, T. 11 N., R. 4 E., where three or four flows totaling about 350 feet in thickness rest on the uppermost sandstone beds of the Clews fanglomerate. From here the basalt extends eastward to the SW¼ of sec. 4, T. 11 N., R. 4 E., and thins out short of Clews Ridge. Most of the Alvord Peak basalt is on the west flank of the Spanish Canyon anticline. The basalt thins rapidly along the strike northeastward in sec. 30, T. 12 N., R. 4 E. It does not reappear to the northeast except for one small outcrop in the wash in Spanish Canyon in the SE¼ of sec. 19. South of the mouth of Spanish Canyon small outcrops of basalt surrounded by alluvium appear similar to the much larger masses of Alvord Peak basalt on either side of Spanish Canyon; however, they may be slightly younger in age.

Pipes and dikes texturally similar to the Alvord Peak basalt cut the Clews fanglomerate in sec. 32, T. 12 N., R. 4 E., and probably occupy former vents from which some of the flows were extruded.

The Alvord Peak basalt rests comformably on the upper tuffaceous beds of the Clews fanglomerate wherever these two formations are in contact. Northwestward the Alvord Peak basalt overlaps the Clews fanglomerate as the fanglomerate wedges out, and the basalt rests directly on plutonic rocks and granodiorite porphyry dikes of the basement complex. An uneven surface on the Alvord Peak basalt is overlain by the Spanish Canyon formation. To what extent the unevenness of this surface is due to erosion and to what extent it is due to initial irregularity caused by piling up of viscous lava flows could not be determined. The almost total absence of pebbles of Alvord Peak basalt, however, in the basal part of the Spanish Canyon formation suggests that little if any erosion of the Alvord Peak basalt occurred prior to deposition of the Spanish Canyon formation. The Alvord Peak basalt is overlain by the Barstow formation where the Spanish Canyon formation is missing. Westward along the northern slope of Alvord Mountain, as far as the N½ sec. 22 and the W½ sec. 23, T. 12 N., R. 3 E., where the basalt is overlain by granite fanglomerate of late Tertiary or early Quarternary age, the Alvord Peak basalt is overlain by progressively younger beds of the Barstow formation. The relation of the progressively younger deposits to the basalt indicates downwarping of the Tertiary basin and relative immobility of the Alvord Peak basalt and of the granitic basement complex around the basin during deposition of the younger formations. Without such differential downwarping of the Tertiary basin contemporaneous with deposition, a relief of nearly 3,000 feet on Alvord Peak basalt would be required to account for the progressive onlap. Such a relief on the Alvord Peak basalt, which is less than 500 feet thick, seems unlikely.

The thicker sections of the Alvord Peak basalt comprise several flows. Individual flows cannot be easily distinguished because many are very similar in appearance and because contacts between them are generally covered with talus or are otherwise indistinct (pl. 4). The predominant type is a dark-gray to grayish-black nonporphyritic flow rock that is given the field name of basalt. The rock is in places inconspicuously streaked with dark-red hematite specks and in a few places is vesicular to amygdaloidal, depending on the degree of vesicle filling. In thin section the rock is seen to consist of subparallel andesine-labradorite laths, 0.05 to 0.2 mm long, in a hematite-charged glass (*n* about 1.53). Labradorite microphenocrysts as much as 0.5 mm in length are rare and grade downward to the microlites. Rare iddingsite pseudomorphs after relict olivine range from 0.05 to 0.2 mm. Amygdules consist of an outer band of opal(?) and an inner core of an unidentified mineral in cryptocrystalline mosaics.

Andesite is present within the unit mapped as Alvord Peak basalt, though it is less common than basalt. The basal flow exposed in the type section in the west wall of Spanish Canyon (pl. 4) is andesite. Andesite also occurs as flows near the top of the sequence exposed in the basalt gorge between secs. 22 and 27, T. 12 N., R. 3 E. (pl. 1), as intrusive pipes cutting Clews fanglomerate in the SE¼ sec. 32, T. 12 N., R. 4 E., and as flows, possibly intrusive pipes, south of the mouth of Spanish Canyon. The petrography of the andesites is similar to that of the basalts, except that the microlites are andesine. Iddingsite or iron oxide pseudomorphs are less common, and the refractive index of the interstitial groundmass glass is as low as 1.50.

The intrusive pipes and the small andesite outcrops south of the mouth of Spanish Canyon are unique in their high content of quartz monzonite, quartz, and limestone xenoliths. One specimen of andesite, rich in megascopic xenoliths, contains as much as 25 percent quartz and calcite. The calcite is strewn irregularly in small grains among the groundmass. The quartz occurs in larger masses, whose inner part is a granular mosaic probably derived from a quartzite, enclosed by a thin (0.1 mm) shell of radiating recrystallized quartz. The shell of quartz is separated from the andesite groundmass by a thinner shell of calcite 0.05 to 0.1 mm thick. Smaller grains of quartz are completely recrystallized and enclosed by a shell of calcite. From evidence seen in the thin section, it seems likely that some of the flows of andesitic composition may have been derived by contamination of basalt with quartz monzonite and quartz xenoliths. Limestone would of course desilicify the magma, but limestone is much less abundant than quartz monzonite and similar rocks in the Alvord Mountain quadrangle (pl. 1).

Minor pyroclastic beds, in part autoclastic breccias derived from the flows themselves, occur between some flows near the south end of Spanish Canyon. These pyroclastic beds were not studied in detail.

The Alvord Peak basalt was derived from several vents near Alvord Mountain. The intrusive pipes and dikes in sec. 32, T. 12 N., R. 4 E., probably mark the site of the old vents. Basaltic intrusive bodies in basalt are more difficult to recognize, but there are a few places where basaltic plugs apparently have cut earlier flows. On the west side of Spanish Canyon near the southern border of sec. 31, a volcanic plug is exposed in cross section. Alvord Peak itself may contain one or more plugs, but these are not conspicuous and were not mapped in detail. The form and xenolithic content of the isolated alluvium-surrounded basalt exposures south of the mouth of Spanish Canyon indicate that they may be necks rather than flows. The southward increase in pyroclastic material between flows along the walls of Spanish Canyon also suggests that there were some vents at the south end of Alvord Mountain.

The Alvord Peak basalt, like the Clews fanglomerate, is assigned a middle Miocene or slightly older age, on the basis of the middle Miocene vertebrate fossils in the lower member of the overlying Barstow formation.

Certain isolated outcrops mapped as Alvord Peak basalt—for example, the exposures just south of the mouth of Spanish Canyon (pl. 1) and those in a few areas in the N½ sec. 26, the N½ sec. 27, sec. 22, and sec. 23, T. 12 N., R. 3 E., northwest of Alvord Peak—do not have critical contacts exposed. The basalt exposed here may be younger than the main mass of Alvord Peak basalt in the central part of Alvord Mountain. The isolated exposures just south of the mouth of Spanish Canyon are surrounded by alluvium but occur along the projected axis of a synclinal fold of the lower member of the Barstow formation. This structural relation would cease to be anomalous if these basalt outcrops are actually interbedded within the Barstow formation or are intrusive into it. The exposures of questionable Alvord Peak basalt northwest of Alvord Peak occur near the younger nonporphyritic intrusive basalt flow, which is similar to the Alvord Peak basalt but is known to be conformable on the tuffaceous member of the Barstow formation. The presence of a known younger flow that closely resembles the Alvord Peak basalt casts some doubt on the correlation of the other basalt exposures northwest of Alvord Peak. It is also known, however, that these exposures of questionable Alvord Peak basalt underlie the tuffaceous member of the Barstow formation and must therefore be older than this unit (pl. 2). On the basis of petrographic similarity to the main mass of Alvord Peak basalt, these exposures were mapped as Alvord Peak, but the available evidence does not preclude an age assignment slightly younger than the main mass of Alvord Peak basalt.

SPANISH CANYON FORMATION

The Spanish Canyon formation is composed of sandstone, conglomerate, tuff, and basalt flows. It is here named after its type locality near the center of sec. 30, west of Spanish Canyon (pls. 2, 5). The formation is about 300 feet thick at its type locality but wedges out southwestward within half a mile. North of the type locality, westward-dipping beds of the formation extend along the west side of Spanish Canyon and cross the canyon near the east boundary of sec. 19, where the formation swings eastward around the nose of the Spanish Canyon anticline. On the east flank of Spanish Canyon anticline, a fault of large displacement cuts off the southern extension of the formation. South of this fault the formation reappears on the east slope of Clews Ridge and strikes southwest under Quaternary deposits. Thin exposures of the basal white tuff beds occur 1 to 2 miles southwest of Clews Ridge. Beyond the ridge the formation does not crop out at its stratigraphic position between the Alvord Peak basalt and the Barstow formation. One small exposure of the basal white tuffs occurs between the Alvord Peak basalt and the Barstow formation in the NE¼ sec. 25, T. 12 N., R. 3 E. Small downfaulted blocks locally preserve the Spanish Canyon formation in the area of older formations along Spanish Canyon south of the type locality.

The Spanish Canyon formation rests on an irregular surface of the Alvord Peak basalt on the west flank of the Spanish Canyon anticline. On the east flank the basalt is missing, and the Spanish Canyon formation rests on the Clews fanglomerate, in places with apparent conformity.

The Spanish Canyon formation is overlain conformably by the Barstow formation on the flanks of the Spanish Canyon anticline. Thin olivine basalt flows similar to those in the Spanish Canyon formation also occur in the basal part of the overlying Barstow formation. In the NE¼ sec. 25, T. 12 N., R. 3 E., however, arkosic sandstone stratigraphically above the basal bed of the Barstow formation rests on erosional remnants of white tuffs in the basal part of the Spanish Canyon formation.

The lithology of the Spanish Canyon formation is rather heterogeneous. The lower part of the formation consists of lenticular white and olive-gray tuffs interbedded with sandstone and granitic boulder conglomerate. In the most complete exposures two tuff units are each overlain by two sandstone and conglomerate units. The lower tuff unit is the thicker of the two. The upper part of the formation consists of two grayish-black hogback-forming olivine basalt flows, which provide conspicuous, persistent markers in the field. These two olivine basalts are separated by 20 to 80 feet of sandstone or boulder conglomerate where the unit is thicker.

The lower white tuff unit at the base of the Spanish Canyon formation superficially resembles the white tuffaceous section at the top of the Clews fanglomerate. A detailed section of the tuffs at the base of the Spanish Canyon is as follows:

Section of tuffaceous unit in basal part of Spanish Canyon formation at type locality, NW corner SE¼ sec. 30, T. 12 N., R. 4 E.

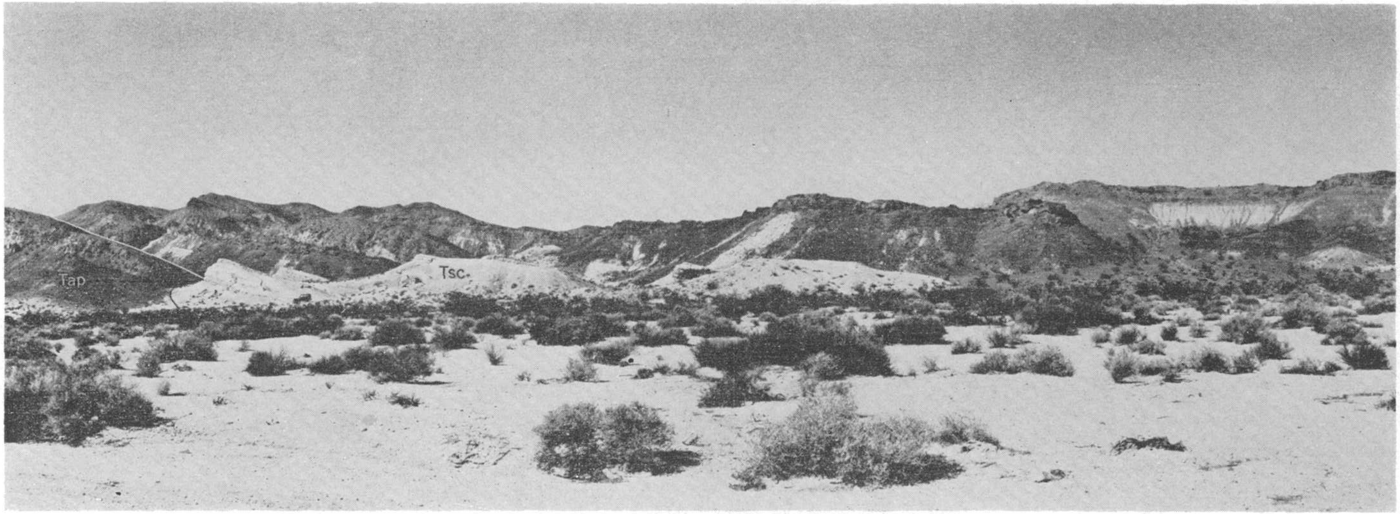
Sandstone, arkosic, yellowish-gray, salt-and-pepper variety, fine- to coarse-grained.	Feet
Sandstone, arkosic, dusky-yellow, fine- to medium-grained tuffaceous	0.5
Sandstone, arkosic, yellowish-gray, medium-grained, tuffaceous, friable	5.0
Tuff, arkosic, mottled yellowish-gray and pale-olive, fine-grained	10.0
Tuff, pebbly, light-gray, coarse-grained	6.0
Tuff, arkosic, very light gray, coarse-grained	2.0
Tuff, bentonitic, very light gray, medium-grained	.5
Tuff, arkosic, white, medium-grained; peppery dark lithic fragments	1.5
Tuff, bentonitic, white, medium-grained; dark fragments	.4
Tuff, siliceous, white, fine-grained; conchoidal fracture	.8
Tuff, bentonitic, white, medium-grained	3.5
Tuff, arkosic, white, medium-grained; peppery dark lithic grains	.5
Tuff, siliceous, white, fine-grained; conchoidal fracture	5.0
Tuff; alternating siliceous (white), and bentonitic (grayish-pink) beds	2.0
Tuff, arkosic, light olive-gray; abundant granules of white tuff and coarse feldspar fragments	6.0
Siltstone, bentonitic, yellowish-gray, tuffaceous, sandy, (arkosic)	6.5
Total measured tuffaceous section	50.2
Siltstone and sandstone, interbedded, arkosic, color gradation downward to moderate reddish-brown, medium- to coarse-grained	11.0
Alvord Peak basalt	40.0

The lowermost tuff, the uppermost tuff, and one of the white tuffs in the middle of the foregoing section were studied in thin sections. All three tuffs are vitric with varying amounts of broken crystals and lithic lava fragments. What was originally cellular glass is now anisotropic, presumably a mixture of opaline silica and montmorillonite. The crystals are largely plagioclase, with subordinate sanidine(?), biotite, hornblende, and muscovite. Many of the plagioclase grains appear as shaggy, irregular remnants in the vitric groundmass. The original fragments in the upper two tuffs examined are well sorted and range from 0.1 to 0.3 mm; crystal and lithic fragments are slightly smaller. The lowermost tuff bed is coarser and contains white cellular fragments 1 to 5 mm in size—the white granules observed in hand specimen. The excellent sorting of these tuffs suggests wind transport, although some local reworking by water prior to final deposition may also have occurred.

Above the lower thick tuffaceous section of the Spanish Canyon formation are interbedded coarse arkosic sandstones and boulder conglomerates (pl. 2). On the east flank of both the Spanish Canyon anticline and Clews Ridge these beds contain boulder fanglomerate with boulders of mafic plutonic rocks like those now exposed in the crystalline core of Alvord Mountain. On the west flank of the Spanish Canyon anticline, the boulder fanglomerate beds are only a few feet thick and contain, in addition to debris of the mafic plutonic rock, rare fragments of nonporphyritic basalt, of pink aplitic granite, and of light-gray to grayish-orange biotite-poor quartz monzonite or granodiorite. The one nonporphyritic basalt fragment observed closely resembles the Alvord Peak basalt, and the pink aplitic granite could also have come from Alvord Mountain. The biotite-poor quartz monzonite, however, closely resembles light-colored granodiorite that borders quartz monzonite in the northwestern part of the quadrangle. It seems possible that these fanglomerates may have had a mixed provenance. Fragments of Alvord Peak basalt, however, should be more abundant in the fanglomerates of the Spanish Canyon formation if the major contribution of debris originated from Alvord Mountain. Perhaps by the time this conglomerate was deposited the washes extended southeastward through ancestral Alvord Mountain, which was just becoming buried in a rising flood of detritus from the northwest.

Two olivine basalt flows in the upper part of the Spanish Canyon formation (pl. 2) are rather constant in thickness over short distances in contrast to the Alvord Peak basalt, but in general they range in thickness from 20 to 60 feet. These two flows erode to prominent hogbacks that aid greatly in identifying major structural features such as the Spanish Canyon anticline. Both flows are commonly present in the upper part of the formation, but they are missing at the small exposure in the NE¼ sec. 25, T. 12 N., R. 3 E., and in the exposures on the south side of Alvord Mountain southwest of Clews Ridge. The underlying sandstone beneath each basalt is grayish pink to moderate orange pink for a few feet below the contact, apparently owing to heat and oxidation at the time the basalts were extruded. Both basalts, particularly the upper one, contain large amygdules of light-gray opaline chalcedony, and some amygdules contain an outer shell of blue-green chrysocolla, which also occurs in veinlets in the upper few feet of the upper olivine basalt.

The olivine basalt occurs as two principal facies: grayish-black nonvesicular finely granular olivine basalt that constitutes the center of the flows, and red-purplish gray amygdaloidal basalt that constitutes the bottom and top parts of the flows. As seen under the microscope, both facies have a seriate ophitic texture. The average grain size in both facies is approximately 0.5 mm, but a few radiating clusters of labradorite laths attain a maximum diameter of 1 cm; individual laths are 4 mm. Olivine and augite range in size from 0.05



SPANISH CANYON FORMATION AT TYPE LOCALITY

Near center of sec. 30, west of Spanish Canyon. The basalt at the extreme left beneath the basal white tuffs of the Spanish Canyon formation (Tsc) is the Alvord Peak basalt (Tap), which wedges out toward the camera. Two olivine basalt flows in upper part of formation cap hogbacks at right.

NORTHEAST-STRIKING NORMAL FAULT

Fault (F) viewed toward southwest nearly along strike. Fine-grained bentonitic beds at base of Clews fanglomerate have been dragged downward against fault. Fanglomerate beds on southeast side of fault are higher in section. SE¼ sec. 29, T. 12 N., R. 4 E., in bottom of wash.

to 1.0 mm. The chief difference between the dark facies and the red-purplish gray facies is in the presence of vesicles, alteration (oxidation), and abundant zeolites and opaline chalcedony in the red-purplish gray facies. The percentages of the rock-forming minerals remain approximately constant if iddingsite is substituted for olivine. The percentages of the minerals in the two facies as measured in thin section by Chayes point counter are given as follows:

	Grayish-black nonvesicular basalt	*Red-purplish gray vesicular basalt*
Labradorite	57	59
Augite	18	17
Olivine	22	0
Iddingsite (hematite)	1	20
Antigorite	1	0
Dark opaque oxide (magnetite?)	1	1
Opal and zeolite	0	3

The source of the two olivine basalts is not known. Their relatively constant thickness over a large outcrop area suggests that they had a high fluidity at the time of their extrusion. The interlocking ophitic texture also indicates that most of the crystallization of these basalts, except possibly that of the larger olivine crystals, was completed in a relatively fluid medium free of crystals. The constant thickness and the indications of fluidity are permissive to the hypothesis that these olivine basalts flowed from a distant source outside of the Alvord Mountain area. In the basal part of the overlying Barstow formation similar olivine basalt flows occur in association with pebble debris known to have come from the area of the Paradise Range northwest of the Alvord Mountain area, and it seems likely that the two olivine basalt flows in the upper part of the Spanish Canyon formation also came from vents situated somewhere to the northwest.

The age of the Spanish Canyon formation is known with slightly more certainty than the ages of the underlying formations. Wherever the olivine basalt flows are present, a similar succession of beds, including one to three thin olivine basalts similar to those of the Spanish Canyon, may be seen in the overlying Barstow formation. The extent of both the olivine basalts and the overlying succession in the Barstow formation indicates that the Barstow is conformable on the Spanish Canyon. A middle Miocene horse, *Merychippus tehachapiensis* of Phillips Ranch affinities (Buwalda and Lewis, 1955), has been found 400 to 500 feet above the top of the Spanish Canyon formation. Therefore, the Spanish Canyon and the lower 500 feet of the Barstow cannot be younger than middle Miocene. Inasmuch as the two formations are conformable and contain similar olivine basalt flows, it is likely that the Spanish Canyon is of middle Miocene age, although the possibility of an early Miocene age for at least the lower part of the formation cannot be eliminated.

The 50-foot section of tuff beds at the base of the Spanish Canyon formation may be correlative with similar pyroclastic rocks elsewhere in the central Mojave Desert. These tuffs record the maximum-explosive volcanism of silicic rocks in the Tertiary system as exposed at Alvord Mountain. This volcanism, however, occurred some distance from Alvord Mountain, for the basal tuffs of the Spanish Canyon formation contain fine-grained wind-transported shards. These fine-grained tuffs should therefore be represented closer to the source by a thicker pile of coarse tuff-breccias. The prevailing wind then as now was probably from the Pacific Ocean to the west, and hence the source area of the tuffs and of a thicker pile of tuff-breccias probably lay west of Alvord Mountain. In the Calico Mountains in the Lane Mountain quadrangle to the west, a thick volcanic pile consists of andesite to dacitic tuff, tuff-breccia, and agglomerate (McCulloh, written communication, 1955) and is also overlain by the Barstow formation, which contains in its upper part vertebrate fossils similar to those found in the Barstow formation at the Alvord Mountain localities (G. E. Lewis, written communication, 1953; McCulloh, 1954, p. 22; oral communication, 1953). According to Robert G. Schmidt (oral communication, 1954), who has made a microscopic study of specimens of pyroclastic beds from both areas, the thick volcanic sequence in the Calico Mountains mapped by McCulloh is correlative at least in part with the white tuffs at the base of the Spanish Canyon formation. From the above evidence it is tentatively inferred that the Spanish Canyon formation is of middle Miocene age.

BARSTOW FORMATION

GENERAL GEOLOGIC FEATURES

The Barstow formation, as presently accepted by the U.S. Geological Survey (Wilmarth, 1938, p. 119), was named and described by J. C. Merriam (1915, p. 252–254; 1919, p. 440–448). Fossiliferous Miocene beds at the type locality in the Barstow syncline, 10 miles north of Barstow, Calif. (fig. 1), were thought by Merriam to contain only upper Miocene vertebrate fossils, but in the lower part of the type section, vertebrate fossils assigned to middle Miocene age have been recognized (G. E. Lewis, written communication, 1954).

In the eastern part of Alvord Mountain, clastic and tuffaceous beds that are characterized by lithology and vertebrate fossils similar to or identical with those found in the Barstow formation at the type locality are assigned to the Barstow. The Barstow formation crops out in upper Spanish Canyon in secs. 19 and 30 on the west flank of the Spanish Canyon anticline (pl. 1), where it is about 1,250 feet thick (pl. 2). To the west along the north slope of Alvord Mountain progressively higher beds of the Barstow formation rest on the Alvord Peak basalt and the pre-Tertiary rocks. From upper Spanish Canyon the Barstow formation strikes southeastward along the east flank of the Spanish Canyon anticline where it attains an approximate maximum thickness of 1,500 feet; faulting precludes exact measurements. The Barstow formation also crops out east and south of Clews Ridge and strikes generally southwest; minor variations in strike are due to folding and faulting. At the mouth of Spanish Canyon the formation is folded into a westward-plunging syncline. In one isolated exposure in the northwesternmost part of Alvord Mountain, tuffaceous beds of the Barstow formation rest on base rock in the SW¼ sec. 28, T. 12 N., R. 3 E.

The Barstow formation lies conformably on the Spanish Canyon formation and rests unconformably on older formations. The upper contact is conformable and gradational with overlying granitic fanglomerate in the downfaulted block of fanglomerate at the northwest corner of sec. 30, T. 12 N., R. 4 E. The main contact, however, around the north side of Alvord Mountain is a slight angular unconformity, in which the upper part of the Barstow and the lower part of the granitic fanglomerate are missing. The channeling into the Barstow formation by the granitic fanglomerate is on a sufficiently gross scale in the NW¼ sec. 25, T. 12 N., R. 3 E., to show on the geologic map (pl. 1). On the southern flank of Alvord Mountain the granitic fanglomerate overlies the Barstow formation with angular unconformity.

The Barstow formation is divided for descriptive and mapping purposes into a lower member, a tuffaceous middle member, and an upper member (pl. 2). The tuffaceous middle member was mapped separately on plate 1 because it forms a useful marker bed. The lower and upper members are not differentiated on the geologic map but are obvious wherever the tuffaceous middle member is present (pl. 1). In the upper part of Spanish Canyon the lower member contains a thin olivine basalt flow 250 to 300 feet above the base; this flow is somewhat more persistent laterally than two similar flows that are in the lower member at apparently lower stratigraphic positions south of Clews Ridge (pl. 1). A nonporphyritic basalt plug is continuous with a basalt flow that extends laterally above the middle member in secs. 26 and 27, T. 12 N., R. 3 E.

LOWER MEMBER

The lower member of the Barstow formation attains a maximum thickness of about 900 feet and consists of 500 to 600 feet of interbedded sandstone and pebble conglomerate, overlain by 200 to 300 feet of tuff, tuffaceous sandstone, siltstone, and volcanic pebble conglomerate (pl. 2). The conglomerate beds in the lower 500 to 600 feet contain conspicuous rectangular fragments of banded siliceous pre-Tertiary argillite, particularly in exposures west of the Spanish Canyon anticline. Such argillite is not exposed in the crystalline core of Alvord Mountain but is exposed in the Paradise Range, 15 miles to the northwest in the Lane Mountain quadrangle (McCulloh, oral communication, 1953). East of the Spanish Canyon anticline these fragments are less abundant and pebbles of grayish red-purple lava of Tertiary age are common. In the outcrop area east and southeast of Clews Ridge, fragments of dark schist, gneissoid quartz monzonite, granite pegmatite, and white quartz, probably of local origin, predominate over the banded argillite and volcanic pebbles (pl. 2). The three olivine basalt flows, in the interval 150 to 300 feet above the base, are well exposed in cuts along the private road of the Los Angeles Bureau of Power and Light (NW¼ sec. 10, T. 11 N., R. 4 E.). These basalts are 20 feet or less in thickness and in places are highly altered. The upper 200 to 300 feet of the lower member contains two or three white vitric ashy tuff beds overlain by conglomerates with extremely well-rounded, light-gray and grayish red-purple porphyritic andesite pebbles and cobbles. These volcanic boulders are not hydrothermally altered and are probably derived from a source area of Tertiary volcanic rocks, probably Miocene in age. Friable siltstone overlies the andesite cobble beds in places where they are thin. Just north of Clews Ridge (pl. 2), the lower member is somewhat more tuffaceous.

TUFFACEOUS MIDDLE MEMBER

The tuffaceous middle member of the Barstow formation, as mapped on plate 1, comprises two or three, rarely more, friable white granular tuff beds and intervening clastic beds. The member varies greatly in thickness, depending mainly on the amount of clastic material between tuff beds. The lowermost part of the upper member in the northwestern part of Alvord Mountain, where most of the upper member is missing, is mapped with the middle member to avoid confusion of lines on the geologic map (pl. 1). The thickness, grain size, and number of the tuff beds increase toward the west and suggest that the source vents were west, possibly northwest, of Alvord Mountain. Stratigraphic sections of the tuffaceous middle member, as mapped on plate 1, and overlying tuffaceous beds are shown in figure 2. The total thickness of tuff in the westernmost measured section is about 20 feet in contrast to about 10 feet in the three measured sections to the east (fig. 2). Furthermore, the fragments in the tuffs of the westernmost section are almost all of lapilli size, rather than of granule size as are the fragments in the

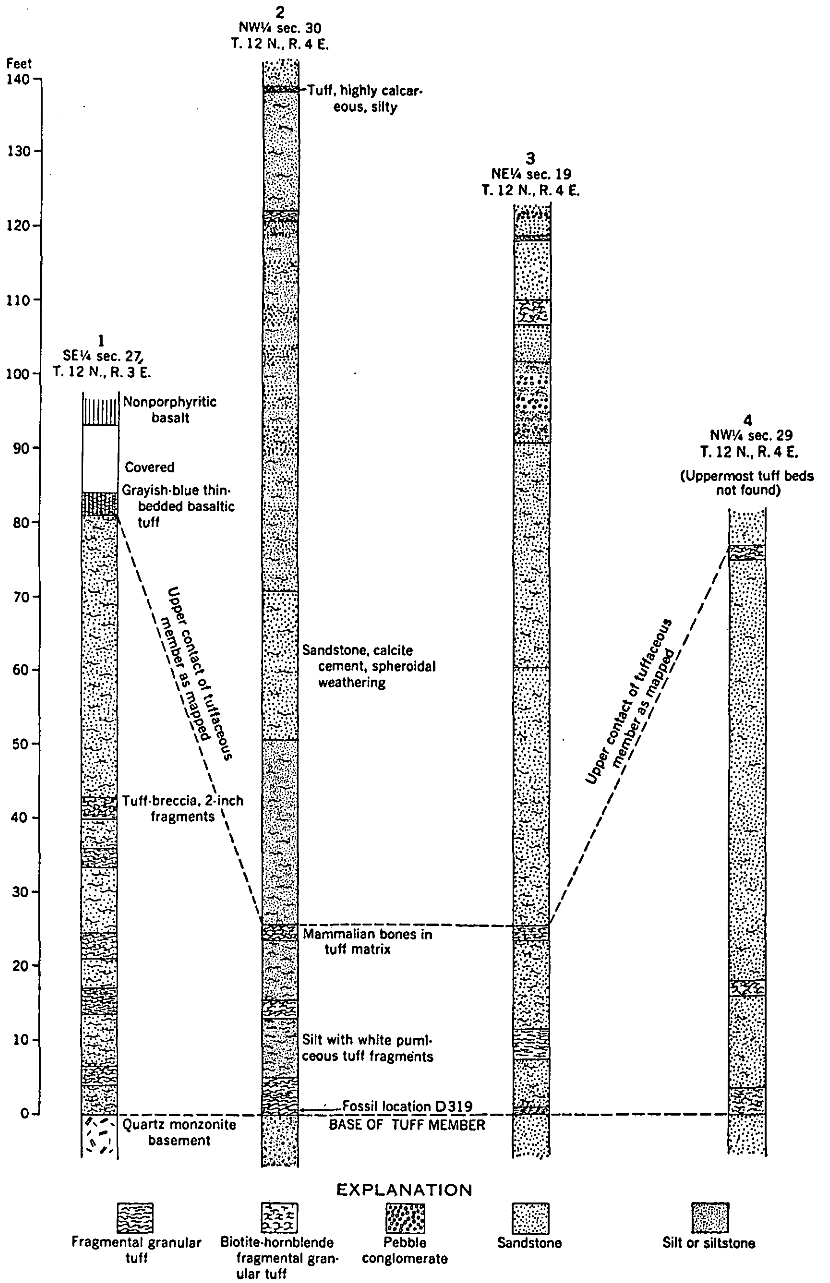


FIGURE 2.—Stratigraphic sections showing lateral changes from west to east in tuffaceous middle member of Barstow formation and in overlying tuffaceous beds along the north side of Alvord Mountain.

tuffs of the eastern sections. The source vent may have been near the northwestern part of Alvord Mountain, possibly at the site of the vent that extruded the overlying basalt.

The tuff beds are frangible, poorly consolidated, granular, and pumiceous. When struck with a geologic pick, they resound with a dull thud, and a large specimen weighing many pounds may spall off. Many of the white pumice fragments in the tuff are near lapilli or pea size. The matrix includes glass shards and a minor amount of light yellowish-gray silt or fine sand. The lowermost tuff bed (fig. 2, sections 2, 3, and 4) does not contain as much biotite as the two above. The tuff beds contrast petrographically with those of the Spanish Canyon formation in having larger grain size and in containing unaltered volcanic glass with a greater degree of vesiculation. Most of the glass is pumice.

NONPORPHYRITIC BASALT INTRUSION AND FLOW

A nonporphyritic basalt intrusive plug and flow is exposed northwest of Alvord Peak in the W½ sec. 26 and the NE¼ sec. 27, T. 12 N., R. 3 E., (pl. 1). The topographically lower part of the basalt near the center of sec. 26 has nearly vertical contacts with quartz monzonite and is probably intrusive near the bottom of the gully. The basalt must also intrude the tuffaceous member of the Barstow formation, but the contact is covered by talus. The vent of the basalt is thereby exposed, and the basalt actually changes from an intrusive plug to a flow as the basalt mass spreads upward and westward. The flow part of the basalt has a maximum thickness of about 100 feet and rests on the tuffaceous member of the Barstow formation.

The basalt closely resembles the Alvord Peak basalt and is nonporphyritic except for sparse hypersthene phenocrysts, 0.5 to 1.0 mm long, and lath-shaped labradorite microphenocrysts that grade downward in size to coarse microlites. The groundmass, which constitutes nearly all the rock, consists of plagioclase, opaque oxides, augite, and interstitial brown glass. Four to five feet of grayish-blue thin-bedded basaltic ash, not observed elsewhere in the Alvord Mountain quadrangle, is exposed beneath the basalt flow where a gully intersects it in the NE¼ sec. 27. The ash probably represents an explosive phase of the eruption that gave rise to the basalt flow.

The age of the nonporphyritic basalt flow and its geologic relation to the Alvord Peak basalt are not entirely clear. That the basalt flow is interbedded with the Barstow formation is suggested by the basaltic grayish-blue ash conformable with the underlying tuffaceous middle member of the Barstow formation. This basaltic ash also has the intimate association with the overlying nonporphyritic basalt that is commonly observed in volcanic fields and that is suggestive of an explosive ash eruption followed by the extrusion of the basalt. Hence, the basalt, as well as the grayish-blue basaltic ash, was most likely erupted during the time interval represented by the Barstow formation. The geologic relation of the nonporphyritic flow to the basalt to the north mapped as Alvord Peak is not clear owing to overlying talus and alluvium and to similarity of the two basalts. As mapped on plate 1, the nonporphyritic-basalt flow was probably extruded down a wash or other topographic depression flanked in late Miocene time by Alvord Peak(?) basalt and pre-Tertiary rocks of the basement complex.

UPPER MEMBER

The upper member of the Barstow formation is about 500 feet thick at the measured section (pl. 2) in the NW¼ sec. 30, T. 12 N., R. 4 E., northeast of Alvord Peak (pl. 1), where the upper member is gradational and conformable with the overlying granitic fanglomerate. This thickness probably holds true for most of the outcrop area as far as a mile west of Spanish Canyon. Westward in the NW¼ sec. 25, T. 12 N., R. 3 E., the upper member is scoured by a channel fill of the overlying granitic fanglomerate. West of sec. 25, T. 12 N., R. 3 E., or northwest of Alvord Peak, the upper member is very thin or nonexistent; it is commonly concealed by bouldery rubble from the overlying granitic fanglomerate. East of the Spanish Canyon anticline the exposed thickness of the upper member ranges from 100 to 400 feet, and in secs. 27, 34, and 35, T. 12 N., R. 4 E., the upper contact becomes one of slight angular unconformity with the granitic fanglomerate. In the NW¼ sec. 2, T. 11 N., R. 4 E., east of Clews Ridge and just north of the private road of the Los Angeles Bureau of Power and Light (pl. 1), the tuffaceous middle member pinches out and the upper and lower members thereby become inseparable.

The sandstone beds in the lower 100 feet of the upper member are silty and tuffaceous west of the Spanish Canyon anticline and in places contain fossil bone fragments like those in the tuffaceous member. Several sandstone beds ½ to 2 feet thick contain calcite cement, but the cement is apparently not uniform, because a characteristic feature of the beds is spheroidal or "knobby" weathering. East of the Spanish Canyon anticline, an andesite cobble conglomerate, as much as 100 feet thick, overlies the tuffaceous member (pl. 2). Above the basal 100 feet, the upper member consists of pebble conglomerate and interbedded sandstone with characteristic grayish-orange (salmon) color. The pebbles in the conglomerate beds west of the Spanish Canyon anticline are grayish red-purple Tertiary andesite-latite, pre-Tertiary banded siliceous argillite, and pale-orange quartz monzonite. The banded argillite and, to a lesser extent, the quartz monzonite indicate a provenance from the northwest; the volcanic pebbles presumably had a similar provenance. One pebble of olivine basalt was also observed, but olivine basalts similar to those in the Spanish Canyon formation may also be exposed in the area to the northwest. Near the northwest corner of sec. 30, T. 12 N., R. 4 E., northeast of Alvord Peak (pl. 2), dioritic boulders, similar to those in the overlying granitic fanglomerate, appear just below the gradational contact with the overlying granitic fanglomerate. The content of volcanic pebbles gradually diminishes to zero up section as the gradational contact zone of the overlying granitic fanglomerate is approached. In the area east of Clews Ridge, the upper member contains pebbles of altered (Mesozoic?) volcanic rocks whose source area is unknown. The nearest altered Mesozoic volcanic rocks crop out some 25 miles east in the Soda Mountains, but, in view of strong conflicting evidence, this area is not believed to be the source of the altered volcanic pebbles in the Alvord Mountain locality.

AGE AND CORRELATION

Vertebrate mammalian fossils, on which an age determination can be based, have been found in two stratigraphic zones in the Barstow formation. U.S. Geological Survey localities D320 and D321 are in sec. 34, T. 12 N., R. 4 E., near the west and south section lines, respectively (pl. 1). These localities are 400 to 500 feet above the base of the lower member of the Barstow formation; the stratigraphic position of these localities, particularly that of locality D320, cannot be determined more precisely because of faulting and incomplete exposures that may conceal existing faults. Locality D321, however, is about 500 feet below the top of the lower member and hence about 400 feet above the base, provided the thickness of the measured section (pl. 2) remains constant. Locality D321 yielded vertebrate bone fragments identified as *Merychippus tehachapiensis* of Phillips Ranch local fauna and Kinnick formation (middle Miocene) affinities (Buwalda and Lewis, 1955).

Vertebrate mammalian fossils were found in the lower member and in the tuffaceous middle member of the Barstow formation at USGS localities D301, SW¼ sec. 19, T. 12 N., R. 4 E.; D319, NW¼ sec. 30, T. 12 N., R. 4 E.; D320, NW¼ sec. 34, T. 12 N., R. 4 E.; and D321, SE¼ sec. 34, T. 12 N., R. 4 E. (pl. 1). These fossils, identified by G. Edward Lewis of the U. S. Geological Survey, and the localities from which they came are as follows:

Locality D301 (tuffaceous middle member):
- *Brachypsalis* cf. *B. pachycephalus*
- *Merychippus* sp. indet.
- *Hesperocamelus*, primitive sp.
- *Merycodus* sp.

Locality D319 (tuffaceous middle member)
Merychippus sp. indet.
Brachycrus buwaldi
Camelid, gen. and sp. indet.
Locality D320 (lower member):
Merychippus sp. indet.
Camelid, gen. and sp. indet.
Locality D321 (lower member):
Merychippus tehachapiensis
?*Merychyus* sp.

According to Lewis (written communications, 1953, 1955, 1957), all these genera except Brachypsalis have been found in the type locality of the Barstow formation, 10 miles north of Barstow, Calif. *Brachycrus* and *Merychyus*, however, occur there some hundreds of feet lower in the section than do characteristic upper Miocene genera and species of the so-called "Barstow local fauna" of "Barstovian" age (Wood and others, 1941, p. 12, 14, pl. 1). *Brachycrus buwaldi* is thought by Schultz and Falkenbach (1949, p. 80, chart 1) to be of the same age as *B. wilsoni* of the Sheep Creek local fauna in the Hemingford group of Lugn (1938, p. 226) in Nebraska, where *B. wilsoni* is associated with *Merychippus primus*, a middle Miocene horse seemingly of the same age as *M. tehachapiensis* from locality D321 on the east end of Alvord Mountain.

The age of the Barstow formation in the Alvord Mountain quadrangle therefore probably includes the transition from middle to late Miocene. The middle Miocene *Merychippus tehachapiensis*, of the Kinnick formation (Buwalda and Lewis, 1955), occurs 400 to 500 feet above the base of the 1,250-foot sequence that constitutes the Barstow formation, and the more advanced late Miocene fauna occurs about 900 feet above the base. *Brachycrus buwaldi*, which occurs several hundred feet below the characteristic upper Miocene mammals at the type locality, is also probably of middle Miocene age (Lewis, written communication, 1955). Thus, the lower 60 percent of the Barstow formation as exposed in the eastern part of Alvord Mountain is most likely of middle Miocene age; the upper member may be mostly of late Miocene age (Lewis, written communication, 1955). That the age of the Barstow formation at the type locality might also extend back into the middle Miocene has been shown by Lewis (written communications, 1953, 1955) who is quoted below:

> The present faunal studies lead to the conclusion that possibly all, and certainly most, of the Barstow formation from 1,700 feet to 2,600 feet above the base represents upper Miocene position (of so-called "Barstovian" age) and that the levels where *Brachycrus* occurs represent middle Miocene position.

The general scarcity of pebble debris derived from Alvord Mountain and the abundance of pebbles derived from areas to the northwest indicate that during the time represented by the deposition of the Barstow formation broad alluvial fans originating to the northwest had largely if not entirely filled the small local basins near Alvord Mountain. Debris, probably derived from the crystalline core of Alvord Mountain, is known only in the lowermost part of the Barstow formation southeast of Alvord Mountain in the inferred direction of drainage. These fans were probably tributary to a playa basin to the south, which was a part of a much larger basin that extended west-northwest beyond the west edge of the Opal Mountain quadrangle, 40 miles west of Alvord Mountain (fig. 1). According to T. W. Dibblee, Jr. (oral communication, 1953), fine-grained sedimentary beds of the Barstow type section grade westward into sandstones and conglomerates that also contain a Barstow fauna in the Black Canyon area of the western part of the Opal Mountain quadrangle. The lithology of the lower part of the Barstow formation at the Black Canyon area in the Opal Mountain quadrangle closely resembles, even to individual tuff beds, the lithology of the Barstow formation in the eastern part of Alvord Mountain.

The fossiliferous part of the Barstow formation at Alvord Mountain is probably continuous, under alluvial cover, with similar fossiliferous Barstow formation in the Daggett quadrangle to the southwest. Beds of calcareous sandstone, sandy limestone, and opaline chert, which resemble the upper part of the Barstow formation in the northeast corner of the Daggett quadrangle, crop out 2 miles south of the southern border of the Alvord Mountain quadrangle just north of U.S. Highway 91–466 about 3 miles west of Manix, or about midway between exposures at Alvord Mountain and in the Daggett quadrangle. These beds are overlain either conformably or with low angular unconformity by volcanic gravels that resemble a unit which also overlies the fossiliferous Barstow formation near the northeastern corner of the Daggett quadrangle, 5 miles to the west (McCulloh, written communication, 1955).

Within the central Mojave Desert, the present known extent and lithology of Tertiary beds containing vertebrate fossils similar to those at the type locality of the Barstow formation suggest that the basin in which the formation was deposited during middle and late Miocene time included the Alvord Mountain area and extended at least 40 miles to the west. The central part of the basin containing the fine-grained facies probably was near the Calico Mountains in the northern half of the Daggett quadrangle, but there may also have been a west-northwest chain of playas separated by gravel fans, such as the present north and south playa basins of Panamint Valley.

One such middle and late Miocene playa is known in the core of the Black Canyon anticline at the west edge of the Opal Mountain quadrangle, another is known at the east end of the Barstow syncline near the east edge of the Opal Mountain quadrangle, and another may have existed beyond the southern border of the Alvord Mountain quadrangle.

LATE TERTIARY AND EARLY QUATERNARY ROCKS

GRANITIC FANGLOMERATE

Granitic fanglomerate is exposed extensively throughout the inward-facing escarpment and low hills that flank Alvord Mountain on the southeast, east, northeast, and north (pl. 1). Exposures of granitic fanglomerate in secs. 9 and 10, T. 12 N., R. 3 E., northwest of Alvord Mountain, extend discontinuously westward into sec. 22, T. 12 N., R. 2 E., of the Lane Mountain quadrangle. Southeast of Langford Well Lake the granitic fanglomerate is exposed in a dissected anticlinal hill. The thickness of the granitic fanglomerate reaches a maximum of about 1,000 feet at the west-plunging nose of the Spanish Canyon anticline near the center of the quadrangle. Elsewhere, the granitic fanglomerate is incompletely exposed and the total thickness is unknown. Flat-lying or very low dipping granitic fan gravels that may be much younger than the folded fanglomerate have also been mapped as granitic fanglomerate because the contact between the gravel and fanglomerate is everywhere covered or poorly exposed.

The granitic fanglomerate lies unconformably on the Barstow and older formations except in one locality, the down-faulted block at the northwest corner of sec. 30, T. 12 N., R. 4 E., (pl. 1), where the granitic fanglomerate grades downward into the Barstow formation (pl. 2). The contact around the northern edge of Alvord Mountain is mainly one of slight angular unconformity. Just west of the nose of the Spanish Canyon anticline, granitic fanglomerate that dips 15° overlies beds of the Barstow formation that dip 30° to 35°. Along the steeply dipping northeast flank of the Spanish Canyon anticline, the Barstow formation dips 60° to 70°, whereas the maximum dip in the overlying granitic fanglomerate is 40°. In the northeastern part of Alvord Mountain (SW¼ sec. 27, T. 12 N., R. 4 E.), the granitic fanglomerate dips 7° northeast and the underlying Barstow formation dips 17° northeast. Three-fourths of a mile south of the mouth of Spanish Canyon, beds mapped as granitic fanglomerate dip less steeply than the Barstow formation in nearby exposures. In the northwestern part of Alvord Mountain, the granitic fanglomerate overlaps the Barstow formation westward onto the underlying Alvord Peak basalt and the basement complex.

East and southeast of Alvord Mountain, the granitic fanglomerate is overlain with angular discordance by gently dipping volcanic gravel. In several places within a mile or two southeast of the private road of the Los Angeles Bureau of Power and Light (pl. 1), gently dipping beds of the volcanic gravel rest on eroded edges of the granitic fanglomerate that dips as much as 30°. East of Alvord Mountain, near the southeast corner of sec. 2, T. 11 N., R. 4 E., granitic fanglomerate that dips 25° is overlain by coarse breccia derived from nearby basement areas of mica schist. Northwest of Alvord Mountain the granitic fanglomerate intertongues with breccia that in part underlies it south of the Coyote Lake fault.

The granitic fanglomerate is composed of well-sorted boulder beds with minor interbedded pebbly sandstone. The beds range from 1 to 20 feet in thickness. The lower 100 to 200 feet of the granitic fanglomerate, especially where it is conformable on the Barstow formation, consists of coarse gray arkosic pebbly sandstone interbedded with fanglomerate composed of rounded boulders of gray granodiorite, diorite, and gneissoid diorite. This gray diorite interval grades upward into light-gray fanglomerate composed of well-rounded but poorly sorted boulders of light-colored quartz monzonite or granodiorite averaging from 6 inches to 1 foot in diameter. Toward the west and north from Alvord Mountain the size of the boulders increases. In the anticlinal hill southeast of Langford Well Lake and in exposures along the Camp Irwin Military Reservation boundary, 1 to 2 miles from the west border of the quadrangle, the fanglomerate is composed of unsorted, subangular fragments and boulders, as large as 6 feet in diameter, of quartz monzonite, porphyritic granodiorite, banded argillite, and rare limestone. South and southeast of Alvord Mountain, the granitic fanglomerate contains a varying admixture of limestone and other basement rocks similar to those exposed in the crystalline core in the western part of Alvord Mountain. Southeast of Alvord Mountain one or two exposures of fanglomerate that dip 25° to 30° also contain grayish-red-purple andesite cobbles similar to those in both the underlying Barstow formation and the overlying volcanic gravel. These exposures are assigned to the granitic fanglomerate because they occur as inliers surrounded by gently dipping volcanic gravel.

The granitic fanglomerate is less indurated than the Barstow formation but is somewhat more indurated than the average Quaternary gravel. In outcrop the granitic fanglomerate erodes to low gravel ridges, with the exception of the steep inward-facing escarpment northeast of Alvord Mountain.

The source of the granitic fanglomerate was almost certainly to the northwest of Alvord Mountain. The fanglomerate was largely derived from light-colored quartz monzonite and granodiorite that is now exposed over large areas in the northwestern part of the Alvord Mountain quadrangle, in northern Lane Mountain quadrangle, and in much of the Goldstone Lake quadrangle. The fanglomerate was apparently not derived from the Tiefort Mountains area to the north and northeast, for in that area exposures are mostly schist and gneiss, boulders of which are absent or rare in the granitic fanglomerate. The increase in size of the boulders toward the northwest indicates that the source area was in that direction. Only south and southeast of Alvord Mountain does the granitic fanglomerate contain boulders of schist and gneiss that apparently came from the crystalline core in the western part of Alvord Mountain. The absence of Tertiary volcanic detritus in the granitic gravel, except in a few exposures southeast of Alvord Mountain, suggests either that detritus from these rocks, such as the Alvord Peak basalt and the volcanic rocks of Lane Mountain in the northwestern corner of the quadrangle, was not washed into the basin in which the fanglomerate is now exposed, or that the fanglomerate was deposited prior to the eruption of the volcanic rocks. The latter possibility is preferred, for similar relations exist between folded granitic fanglomerate and less folded volcanic gravels in the Tiefort Mountains and Red Pass Lake quadrangles, to the north and northwest, respectively, of the Alvord Mountain quadrangle. Moreover, rather extensive areas of volcanic rocks of Lane Mountain or their equivalent rest on eroded quartz monzonite, which is abundantly represented in the granitic fanglomerate. Hence, volcanic pebbles would be expected in greater abundance in the granitic fanglomerate if the volcanic rocks were in existence during the accumulation of the fanglomerate.

The age of the basal part of the granitic fanglomerate in the downthrown fault block west of upper Spanish Canyon could be as old as late Miocene, inasmuch as the granite fanglomerate is here locally conformable and gradational into the underlying Barstow formation of middle and late Miocene age. However, the fact that around the north edge of Alvord Mountain the upper part of the fanglomerate lies uncomformably on the Barstow and older formations indicates a hiatus between deposition of the Barstow formation and the fanglomerate; hence, in these areas the fanglomerate is more likely to be no older than Pliocene.

The youngest age of the fanglomerate is uncertain. The fanglomerate is older than the volcanic gravel of probable Quaternary age that overlies it with slight discordance southeast of Alvord Mountain. The moderate degree of deformation and general dissection by erosion of the granitic fanglomerate favors the hypothesis that it is of Tertiary rather than Quaternary age, although this folding and dissection could have occurred as late as early and middle Quaternary time. On the basis of the above evidence it seems likely that the granitic fanglomerate is of Pliocene age, but it may be in part of early Quaternary age. Hence it is tentatively assigned a Pliocene and Pleistocene age.

BRECCIA AND FANGLOMERATE

The breccia and fanglomerate, in contrast to the granitic fanglomerate, consist of shattered angular blocks of pre-Tertiary schist and coarse-grained gneiss of intermediate composition; they were locally derived and occur near major faults (pl. 1). The breccia is generally devoid of bedding and contains blocks as large as 20 feet in width. Breccia occurs in association with the faulting east of Langford Well Lake, south of the Coyote Lake fault in secs. 7, 8, 9, 16 and 17, T. 12 N., R. 3 E., north and south of the Bicycle Lake fault zone, and north and south of another east-trending fault in secs. 11 and 12, T. 11 N., R. 4 E. Outward away from the faults, the breccia commonly grades into a bedded fanglomerate of angular boulders.

The geologic relations between the breccia fanglomerate and the granitic fanglomerate are such as to imply that they were deposited at about the same time. A lens of breccia is intercalated within granitic fanglomerate near the northeast corner of sec. 12, T. 12 N., R. 4 E. The main mass of breccia and fanglomerate south of the Coyote Lake fault in secs. 16 and 17, T. 12 N., R. 3 E., underlies the granitic fanglomerate, but intertonguing relations through a stratigraphic range of 100 feet prevail at the inferred contact shown on plate 1. In a hill in secs. 1 and 2, T. 11 N., R. 4 E., breccia without discernible bedding overlies the granitic fanglomerate. The breccia and fanglomerate in general contain angular blocks derived from nearby pre-Tertiary metamorphic rock in contrast to the rounded boulders that characterize the granitic fanglomerate.

The origin of the breccia, insofar as could be determined from field relations in the Alvord Mountain quadrangle, probably starts with movement along the major faults, along which pre-Tertiary basement rocks have been sheared, brecciated, and elevated and thus prepared for movement downslope. The final movement of the blocks into accumulations is probably largely by gravity. Somewhat more extensive accumulations of breccia associated with major faults were described by Longwell (1951, p. 349–350) and by Woodford and Harriss (1928, p. 287–290).

The age of the breccia and fanglomerate, like that of the granitic fanglomerate, probably ranges from late Tertiary (Pliocene?) through early Quaternary.

HORNBLENDE ANDESITE

A medium light-gray hornblende andesite lava completely surrounded by alluvium occurs near the eastern border of the quadrangle in sec. 24, T. 12 N., R. 4 E. The flow is similar in texture and mineral content to flows exposed within a few miles to the east in the Cave Mountain quadrangle, where they are reported to overlie upper Miocene beds unconformably (J. F. McAllister, oral communication, 1955). In thin section about one-third of the rock is seen to consist of microphenocrysts of andesine-labradorite and basaltic hornblende. Opaque oxides rim the basaltic hornblende and also occur as pseudomorphs after hornblende. The ground mass consists of pilotaxitic laths of oligoclase enclosed by potash feldspar and glass, whose index is about 1.525. This lava can be dated only as younger than late Miocene and older than alluvium; hence, this flow is tentatively assigned a late Tertiary and early Quaternary age, though a middle or late Quaternary age assignment cannot be eliminated on the evidence now available.

VOLCANIC ROCKS OF LANE MOUNTAIN

GENERAL GEOLOGIC FEATURES

Dacitic and rhyolitic rocks and associated tuffaceous sediments crop out in two principal exposures in the northwesternmost part of the quadrangle (pl. 1). The more westerly exposure consists of rhyolitic tuff-breccia and intrusive dacite. These rocks extend westward into the Lane Mountain quadrangle, where they are typically exposed (McCulloh, written communication, 1954). The more easterly exposure consists of about 350 feet of tuffaceous bedded sediments. A tuff bed within these sediments contains broken fragments of rhyolite that are similar to fragments in the tuff-breccia to the west, and the next overlying bed contains fragments of the dacite that to the west is intrusive into the tuff-breccia. Because of this association, the tuffaceous sediments are considered a part of the volcanic rocks of Lane Mountain and locally preserve the record of volcanic activity away from the central vent areas. The tuff-breccia rests on rocks of the pre-Tertiary basement complex; the tuffaceous sediments have been protected from erosion by olivine basalt, by which they are conformably overlain.

RHYOLITIC TUFF-BRECCIA AND DACITE INTRUDED IN TUFF-BRECCIA

Very light gray to white rhyolitic tuff-breccia completely encloses the pale-red dacitic intrusive mass which is probably a plug. Both the bedding and the basal contact of the tuff-breccia on the pre-Tertiary rocks dip 15° to 25° inward toward the dacitic intrusive body, but the bedding and the contact with the plug are nearly vertical. Near the intrusive dacite, the rhyolitic tuff-breccia becomes agglomeratic, loses its whitish appearance, and contains fragments of the dacite. In most places the contact is gradational, but the north contact near the west edge of the quadrangle is sharp and vertical. Along the east side the contact is highly irregular, with pipelike protuberances of dacite extending into the tuff-breccia. The field relations indicate that the dacite fills a volcanic vent. The dacite plug was probably intruded as viscous material into a loosely, consolidated tuff-breccia that was on the surface near the volcanic vent. The base of the dissected volcanic cone is exposed at the lower contact of the tuff-breccia mass on basement rock around the outer edges.

Light-gray felsitic fragments in the tuff-breccia are classified as rhyolite on the basis of a chemical analysis (table 2). The rhyolite consists of microphenocrysts of sanidine, quartz, and lath-shaped oligoclase, 0.05 to 0.1 mm, embedded in the glass of index 1.505.

TABLE 2.—*Chemical analyses of rhyolitic fragments, volcanic rocks of Lane Mountain*

[Henry Kramer, analyst]

Constituent	Locality of sample: In tuff-breccia, NW¼ sec. 11, T. 13 N., R. 2 E.	Locality of sample: In bedded sandy tuff, SW¼ sec. 1, T. 13 N., R. 2 E.
SiO_2	68.55	67.49
Al_2O_3	14.70	15.21
Total iron as Fe_2O_3	1.15	1.25
MgO	.49	.83
CaO	1.83	1.65
Na_2O	1.69	2.17
K_2O	4.89	4.34
Loss on ignition	6.49	6.76
TiO_2	.09	.14
MnO	.05	.04
P_2O_5	.01	.03
Total	99.94	99.91

The dacite is pale red in its glassy parts, mottled with grayish orange pink in the lithic areas. Rare microphenocrysts of andesine are embedded in a smoky glass of index about 1.505 (Allen, written communication, 1954). The lithic phase is anistropic, is stained with hematite dust, and has an average index of 1.52. The rock is tentatively called dacite because of the presence of andesine and low index glass, but a chemical analysis might well prove the rock to be rhyolite, like the fragments in the tuff-breccia.

TUFFACEOUS SEDIMENTS

West of the Barstow-Camp Irwin highway the tuffaceous sediments of the volcanic rocks of Lane Mountain form a conspicuous white exposure beneath grayish-black olivine basalt. A measured section is given as follows:

Section of tuffaceous sediments along line between secs. 1 and 2, T. 13 N., R. 2 E.

	Feet
Olivine basalt.	
Tuff, siliceous, mottled yellowish- to brownish-gray; weathers blocky	30
Sandstone, light-gray; spheroidal weathering; tuffaceous near top	40
Limestone, light-gray, with opaline chert	2
Opaline chert, banded white and brownish gray	1
Tuff, siliceous, white, blocky; becomes bentonitic toward north	5
Sandstone, tuffaceous, light-gray, massive	25
Lapilli tuff; angular fragments of gray lava	1
Tuff, sandy, very light gray, thin-bedded	15
Sandstone, tuffaceous, silty, light-gray, fine	20
Tuff, arkosic, granular, white	6
Siltstone, yellowish-gray, with blocks of dioritic intrusive rock; toward top are many fragments of pale-red dacitic lava like intrusive mass exposed 1 mile southwest	65
Tuff, sandy, very light gray, thin-bedded; coarse beds contain angular fragments of light-gray rhyolite (see table 2) similar to those in tuff-breccia 1 mile to SW	62
Sandstone, tuffaceous, pale-olive to moderate greenish-yellow; contains several interbeds, ½ to 2 ft thick, of conglomerate composed of angular diorite fragments. Unit wedges out within short distance, owing to original uneven surface of basement rock	75
Total measured section	347
Diorite basement.	

AGE OF VOLCANIC ROCKS OF LANE MOUNTAIN

The geologic age of the volcanic rocks of Lane Mountain is based largely on inference. McCulloh (written communication, 1954) on stratigraphic and geomorphic evidence tentatively assigned the volcanic rocks of Lane Mountain at the type locality, to late middle and upper Pliocene age, though he (oral communication, 1954) realized they may be as young as early Quaternary. The degree of folding and depth of erosion of these volcanic rocks in the northwestern part of the Alvord Mountain quadrangle suggest that they are hardly younger than middle Pleistocene nor older than Pliocene.

OLIVINE BASALT

An olivine basalt flow, about 50 feet thick, conformably overlies the tuffaceous sediments of the volcanic rocks of Lane Mountain in secs. 1 and 2, T. 13 N., R. 2 E., along the northern border of the quadrangle. A small outlier of olivine basalt just south of the line between secs. 1 and 12 appears to rest directly on pre-Tertiary dioritic intrusive rock. Talus obscures the contact relations, however, and this outlier of olivine basalt may actually be an intrusive pipe, possibly the vent from which the olivine basalt was extruded. In hand specimen the rock is dark gray and finely granular; weathered surfaces are pale brown with an appearance like fine-grained diabase. This olivine basalt, like the olivine basalts of the Spanish Canyon formation of Alvord Mountain, has a subophitic texture with the following percentages of minerals: Labradorite, 66; olivine (partly altered to iddingsite), 22; augite, 15; and opaque minerals, 2. The slight pleochroism in yellow and faint purplish smoke-gray of the augite suggests a higher than normal titanium content. The olivine basalt was probably extruded within a brief geologic time interval after the deposition of the volcanic rocks of Lane Mountain, but the geologic age can only be surmised as either latest Tertiary or Quaternary. If the flow is of Quaternary age, it is probably early Quaternary, for it is conformable on the volcanic rocks of Lane Mountain and has been tilted and subsequently eroded.

VOLCANIC GRAVEL

The volcanic gravel crops out mainly in the southeastern part of the quadrangle, where the gravel dips gently east to south away from Alvord Mountain (pl. 1). The maximum thickness is probably not more than 200 feet. Two small isolated exposures of moderately folded volcanic gravel with dips of as much as 30° are exposed at the southern border of the quadrangle in sec. 31, T. 11 N., R. 3 E. This moderately folded gravel may be part of a somewhat thicker and older sequence. The volcanic gravel rests unconformably on the eroded edges of the granitic fanglomerate. The contact between volcanic gravel and breccia in the SE¼ sec. 2, T. 11 N., R. 4 E., is not clearly exposed.

The volcanic gravel consists predominantly of pebbles and cobbles of light-gray to grayish red-purple porphyritic andesite-latite, white calcareous opaline chert, and dark-gray opaline chert. The cherty fragments are subordinate to the volcanic pebbles. Pebbles of other rock types are a small fraction of the total. The two small exposures in sec. 31, T. 11 N., R. 3 E., contain sand and a bed of bentonitic silt interbedded with the volcanic gravel. The bentonitic silt contains a minor amount of saline minerals.

The source of the Tertiary or Quaternary volcanic and cherty pebbles that constitute the volcanic gravel exposed in the southeast part of the quadrangle may be the areas of volcanic rocks of Lane Mountain exposed in the northwestern part of the Alvord Mountain quadrangle and nearby areas of the volcanic rocks in the Lane Mountain and Goldstone Lake quadrangles. Other source areas are possible, however, for Pliocene and Pleistocene volcanic rocks similar to the volcanic rocks of Lane Mountain are widespread in the central Mojave Desert. White calcareous chert is interbedded with tuffaceous sediments of the volcanic rocks in the northwestern part of the

Alvord Mountain quadrangle and also occurs at the top of the Barstow formation, a few miles southeast of the quadrangle. Some reworked volcanic pebbles and chert may also have come from the Barstow formation during upwarping of Alvord Mountain. The Barstow cannot be eliminated as a source of some of the pebbles, but the great volume of volcanic gravel in the Alvord Mountain and Cave Mountain quadrangles suggests that most of the volcanic and white chert pebbles probably came from the extensive area of Pliocene and Pleistocene volcanic rocks, such as the volcanic rocks of Lane Mountain, which are in part still exposed in the Goldstone Lake, Lane Mountain and other quadrangles in the central Mojave Desert. Similar relations between very slightly arched volcanic gravel, conformable to the present surface, and moderately folded granitic fanglomerate have also been observed by the writer in the Red Pass Lake quadrangle, northeast of the Alvord Mountain quadrangle.

The age of the volcanic gravel may be latest Tertiary or early Quaternary, but the only basis for this statement is the general geologic relations. If most of the volcanic pebbles and white chert originated in outcrop areas of the volcanic rocks of Lane Mountain, the gravel would slightly postdate the rocks, which are themselves undated. The slight rather than moderate deformation of the volcanic gravel suggests that it is most likely Quaternary in age. The two exposures of moderately dipping volcanic gravel in sec. 31 in the southwest part of the quadrangle may be equivalent in age to the granitic fanglomerate. These two exposures are only 2 miles northeast of similar exposures of volcanic gravel contiguous in the northeastern part of the Daggett quadrangle with a unit assigned by McCulloh (written communication, 1954) to latest Tertiary or early Quaternary age.

QUATERNARY ROCKS

BASALT FLOWS

Small discontinuous outcrops along the Bicycle Lake fault zone in the northeasternmost part of the Alvord Mountain quadrangle (pl. 1) expose thin basalt flows, not more than 50 feet thick, and may include near-surface intrusive masses. Outcrops of basalt exposed near the northern edge of the quadrangle about 3½ miles north of Langford Well Lake are part of a gently arched flow that extends 1½ miles northwest into the Tiefort Mountains quadrangle. This basalt flow rests on basement rock, which is exposed in gullies that cut through the basalt. The flow is overlain by no other formation; as seen on the air photographs, some of the original constructional surface is apparently still preserved from erosion. Other basalt exposures that may include near-surface intrusions extend along the southernmost branch of the Bicycle Lake fault zone in the northernmost part of sec. 8, T. 13 N., R. 4 E. The large amount of talus and rubble that these exposures shed conceals their contact relations.

The basalt is nonporphyritic, medium dark gray to dark gray, and commonly vesicular. Chemical analyses of two specimens of basalt flow rock are given in table 3. The one specimen (table 3) from the

TABLE 3.—*Chemical analyses of specimens of nonporphyritic basalt flows, northernmost part of Alvord Mountain quadrangle*

[Henry Kramer, analyst]

Constituent	Locality of sample	
	Near center sec. 1, T. 13 N., R. 3 E., 1½ miles SE. of Bicycle Dry Lake	Near SW. corner sec. 5, T. 13 N., R. 4 E.
SiO_2	50.50	50.77
Al_2O_3	15.52	14.47
Total iron as Fe_2O_3	12.25	12.00
MgO	7.99	8.26
CaO	9.07	9.28
Na_2O	1.98	1.95
K_2O	.19	.18
Loss on ignition	.09	.55
TiO_2	2.31	2.19
MnO	.14	.17
P_2O_5	.24	.22
Total	100.28	100.04

southern end of the flow that extends north into the Tiefort Mountains quadrangle contains sparse calcite xenoliths rimmed by hematite and magnetite(?). Xenolithic ghosts of calcite, hematite, and magnetite(?) are strewn through the groundmass in association with laths of labradorite and clinopyroxene, 0.01 to 0.05 mm long. Sparse, shaggy microphenocrysts of olivine, 0.2 to 0.4 mm in diameter, are rimmed by minerals of the groundmass, but the former euhedral outlines are still visible. The other specimen (table 3) from the small flow remnant near the southwest corner of sec. 5, T. 13 N., R. 4 E., contains sparse microphenocrysts of hypersthene and iddingsite pseudomorphs after olivine in a microlitic groundmass of labradorite, clinopyroxene, and magnetite(?). The maximum length of the hypersthene is 2 mm, but the average is close to 0.3 mm; iddingsite pseudomorphs after olivine are slightly smaller. The lengths of the groundmass minerals range from 0.02 to 0.1 mm.

The freshness of the basalt and its slightly dissected character between the fault zone in sec. 1 and Bicycle Lake 1½ miles northwest indicate a relatively young geologic age, probably Quaternary. The basalt is sufficiently old, however, to have been gently warped south of Bicycle Lake, tilted 25° to 40° north in the fault zone, and concealed beneath alluvium; hence, it is probably Pleistocene rather than Recent in age. A large outcrop area of similar basalt, a few miles in extent, also appears just south of the Bicycle Lake fault zone in the Cave Mountain quadrangle in T. 13 N., R. 5 E., and is probably about the same age as the Quaternary basalt exposed in the Alvord Mountain quadrangle. All the basalt in the Bicycle Lake fault zone is similar in appearance and in field relations to the Quaternary basalt at Black Mountain, in the Opal Mountain quadrangle (Dibblee, 1954, p. 1244), 35 miles west of the Alvord Mountain quadrangle. The Quaternary basalts in general differ from the Tertiary basalts by lack of alteration and vesicle filling.

LANDSLIDE AND TALUS DEPOSITS

The deposits of landslide and talus debris are composed of large masses, as much as hundreds of feet in length, of basalt, both Tertiary and Quaternary, that have rolled or slid into place under the force of gravity. These deposits are shown on plate 1 wherever they are sufficiently thick to conceal the underlying deposits. In Spanish Canyon near the center of sec. 6, T. 11 N., R. 4 E., three large masses of Alvord Peak basalt lie astride a fault between intrusive rock and Clews fanglomerate but are not themselves faulted. The basalt masses are out of position with respect to the flows in the adjacent wall of Spanish Canyon and presumably are landslide blocks.

MANIX LAKE BEDS

Manix beds was the formational name given by Buwalda (1914, p. 444) to beds deposited in a Pleistocene lake, which he called Lake Manix. This formation is herein called Manix lake beds to conform to present rules of stratigraphic nomenclature (Ashley and others, 1933, p. 434) and U.S. Geological Survey usage (Wilmarth, 1938, p. 1282).

In the Alvord Mountain quadrangle, the Manix lake beds occur chiefly between the 1,780- and 1,800-foot contours and mark the approximate shoreline of Lake Manix in Pleistocene time. Such deposits occur at the southern border of the quadrangle just north of U.S. Highway 91–466 and also a few miles eastward from Coyote Lake in secs. 8, 17, 20, and 29, T. 11 N., R. 3 E. The Manix lake beds have been divided for mapping purposes into gravel bars at former shorelines, beach ridges composed of wave-worked and wind-blown sand, and bedded silt and fine sand deposited in deeper water.

Fine-grained facies of the Manix lake beds are exposed along U.S. Highway 91–466 and in secs. 8 and 17, 2 miles east of Coyote Lake. A 10-foot exposure of fine silty sand along Highway 91–466 near the southern border of the quadrangle is yellowish gray to light brown, well bedded, and nearly horizontal. A deeper brown coloration with limy nodules and veinlets occurs just below the surface in 4 to 6 inches of pebbly coarse sand above the fine silty sand and suggests a weathered profile. Fine-grained beds are exposed in secs. 8 and 17 and are discontinuously exposed westward and southward in irregular areas surrounded by alluvium and windblown sand south and southeast of Coyote Lake. These latter small exposures are not easily separated from fine-grained deposits of Recent age; however, much of the greenish-gray silt beneath the area of windblown sand was probably deposited in Pleistocene Lake Manix. The fine-grained beds in sec. 8, T. 11 N., R. 3 E., are yellowish-gray to pale greenish-yellow very fine silty sand. A grayish-orange to dark yellowish-orange coloration in the upper 1 foot of the deposit suggests a weakly weathered profile. Much of the silty sand is "fluffy" and contains sodium(?) carbonate and other salines.

The Manix lake beds have been dated as late Pleistocene, probably of Tahoe and Tioga ages (Wisconsin), by Blackwelder and Ellsworth (1936, p. 463). Mammalian vertebrate fossils (Herbert Winters, written communication, 1955) and fossil birds (Howard, 1955, p. 204–205) collected from the Manix lake beds also suggest a late Pleistocene age. In view of the negligible amount of tilting and the weak soil profile of the Manix lake beds in the Alvord Mountain quadrangle, they may be largely of late Wisconsin.

TERRACE DEPOSITS ON BEDROCK

Dissected alluvium on Tertiary or pre-Tertiary bedrock has been shown separately on plate 1 as terrace deposits. Similar dissected deposits, with much intervening Recent alluvium, are included with alluvium. The terrace deposits are not visibly warped and probably are largely latest Pleistocene in age.

OLDER WINDBLOWN SAND

Dissected crossbedded sand, apparently dune deposits, occurs within an area of active dunes northeast of Coyote Lake in sec. 26, T. 12 N., R. 2 E. The sand is well sorted and slightly indurated by carbonate cement. The contact between the dune sand and the Manix lake beds is not exposed, but the fact that the dune sand occurs at a lower elevation than the highest lake bench suggests that the sand postdates Lake Manix. The close geographic association of these carbonate-cemented dunes with Jack Rabbit Spring further suggests that the cementation of the sand occurred in Recent time, as a result of the drying up of saline seepages.

RECENT DEPOSITS

Recent deposits shown on plate 1 include alluvium, windblown sand, and the clay and silt of modern playa lakes. Part of the alluvium, particularly that northeast of Coyote Lake, is dissected by gullies as much as 20 feet deep and is probably late Pleistocene rather than Recent in age. The windblown sand is still actively drifting and has been accumulating since the dessication of Pleistocene Lake Manix; the sand is presently being deposited on the higher crystalline bedrock slopes on the western slope of Alvord Mountain. The present playa surfaces of Coyote and Langford Well Lakes are smooth dry mudflats and are fringed by fragments of dark scoriaceous lava, like many of the playas in the Mojave Desert.

STRUCTURE

REGIONAL STRUCTURAL SETTING

The principal structural features of the rocks in the Alvord Mountain quadrangle are part of a complex fault pattern in the Mojave block (Hewett, 1954a; 1954b, p. 16, 17, pl. 1). The Mojave block for purposes of this report is defined as underlying that area between the Garlock fault on the north and northwest and the San Andreas fault on the southwest (fig. 1). Its east boundary is ill defined because of lack of any major topographic or presently known geologic break, but it may be arbitrarily placed approximately at the 116th meridian. The Mojave block underlies most of the area commonly referred to as the Mojave Desert (Baker, 1911, p. 335–336; Thompson, 1929, p. 5–7; McCulloh, 1954, p. 13). In general most parts of the Mojave block have been rising throughout Cenozoic time and have been subjected to erosion (Hewett, 1954a, p. 14–15), so that much of the pre-Tertiary sedimentary and igneous rocks have been stripped away, leaving semi-mountainous areas of pre-Tertiary crystalline rocks and local basins filled with Cenozoic rocks. These uplifted areas and basins were in part bounded by faults. The major fault pattern of the Mojave block may have been in existence at the beginning of Tertiary time, but much movement on faults within the Mojave block occurred during late Tertiary and Quaternary time inasmuch as beds of Miocene, Pliocene, and probably even Pleistocene age are involved in displacements along major faults. The major faults in the Alvord Mountain quadrangle and also in the area between the quadrangle and the Garlock fault to the north (fig. 1) trend eastward, approximately parallel to the Garlock fault. Tertiary basins and local upwarps, such as Alvord Mountain, evolved during and since Miocene time by a combination of folding and faulting, possibly related to movement on the larger faults.

PRE-TERTIARY FOLDS

Moderate to isoclinal folding has affected the pre-Tertiary metamorphic rocks. The low hills north of Langford Well Lake are composed of metamorphosed sedimentary rock that have been moderately folded along axes that trend several degrees west of north (pl. 1). Within half a mile south of the Bicycle Lake fault zone near the northern border of the quadrangle, the attitude of the bedding and foliation steepens and swings westward, as if dragged by lateral movement along the fault zone. This feature is shown by the metalimestone bed in sec. 8, T. 13 N., R. 4 E., which strikes N. 30° W. and dips moderately in the SE¼ sec. 8 but which in the northern half of sec. 8 steepens to vertical and strikes N. 60° W.

The metalimestone belt in the southwestern side of Alvord Mountain (pl. 1) is possibly on the axis of a sharp asymmetrical fold whose axial plane dips steeply southwest. The fold seemingly is a tightly compressed anticline plunging northwestward at the northwest end of the limestone belt, for steep dips on either side of the limestone belt are in opposite directions, and the overlying gneiss is arched over and around the metalimestone. Toward the southeast the dips on either side of the limestone belt approach parallelism, suggesting that the postulated fold becomes isoclinal. The gold vein of the Alvord mine is near the center of the metalimestone belt and may have been localized along the axis of this hypothetical fold.

The contact of the plutonic rocks in most places is concordant with the foliation in the metamorphic rocks; crosscutting relations were observed only at the granitic dikes. In the Lane Mountain quadrangle to the west, folds in Paleozoic and Triassic rocks are believed by McCulloh (1954, p. 19) to antedate the late Mesozoic intrusive rocks. It should be remembered, however, that intrusive rocks of possible Precambrian age may have been responsible for the moderately high grade metamorphic rocks in the Alvord Mountain quadrangle. Mapping of the pre-Tertiary crystalline rocks was not sufficiently detailed to solve this problem.

CENOZOIC STRUCTURAL FEATURES

Several major faults are believed to control the smaller structural features in the Alvord Mountain quadrangle. These include the Bicycle Lake fault zone in the northeasternmost part of the quadrangle, the east-trending Coyote Lake fault, which passes through the middle of the quadrangle, the Garlic Spring fault, and a few other probable faults of less significance. The major faults are largely concealed by alluvium but can be detected by sheared basement rock, by breccia and angular fanglomerate exposed at intervals along the strike, and by steep dips in the late Tertiary and early Quaternary gravels, but rarely by evidence of offset beds.

BICYCLE LAKE FAULT ZONE

The northernmost major displacement is a shear zone several hundred feet wide in the northern part of T. 13 N., R. 4 E (pl. 1). This fault is named the Bicycle Lake fault zone, because northwestward its middle and northerly branches, along which most of the displacement probably occurred, pass under Bicycle Lake playa, a few miles beyond the northern boundary of the Alvord Mountain quadrangle.

Reconnaissance mapping by the writer in the Tiefort Mountains quadrangle to the north has shown that these two branches of the fault extend northwestward under the alluvium in secs. 5 and 6, T. 13 N., R. 4 E., and emerge through a low bedrock pass at the west end of the Tiefort Mountains. Displaced segments of a vertical limestone bed between the two branches in this pass indicate a left lateral strike-slip movement (Hill, 1947, p. 1670) along the faults. Left-lateral movement (north side moved relatively west) is also suggested within the Alvord Mountain quadrangle by the drag of the vertical limestone bed in the NW¼ sec. 8, T. 13 N., R. 4 E., and by the northerly to westerly bend in the foliation of the gneisses near the fault.

Westward along the southernmost fault of the Bicycle Lake fault zone the width and probably the displacement decrease, for only a few inches of gouge are present where the southernmost fault crosses the north border of the quadrangle in the NE¼ sec. 3, T. 13 N., R. 3 E. The most recent movement on the southernmost fault, as shown by moderate northward dips in the Quaternary basalt flows, indicates that in T. 13 N., R. 4 E., the south side of the fault is upthrown relative to the north side. Westward along the southernmost fault the north side is seemingly upthrown relative to the south side, suggesting either rotational movement or upwarping of the pre-Tertiary basement rock on the north side of the fault. That such upwarping has occurred in Quaternary time is indicated by the warped constructional surface on the Quaternary basalt flow.

The Bicycle Lake fault zone merges with a northeast-trending fault zone near the line of secs. 12 and 13, T. 13 N., R. 4 E., within half a mile of the east border of the quadrangle (pl. 1). At the same place a later cross fault slightly displaces both fault zones. The extension of this fault zone southwestward is indicated by scarps cutting breccia and fanglomerate. The northeast-trending fault zone is probably the boundary fault between the low hills of pre-Tertiary basement rock on the northwest and the alluvial plain on the southeast.

GARLIC SPRING FAULT

The Garlic Spring fault is named after Garlic Spring (SW¼ sec. 11, T. 13 N., R. 3 E.; pl. 1), a well-known spring along the fault. Northwest and southeast of Garlic Spring the fault passes under alluvium, where the fault trace is in places marked by saline efflorescence that is probably derived from evaporation of spring seeps. Northeast of Langford Well Lake, where the fault is well exposed in the pre-Tertiary basement rocks, it dips 45° southwest. Slickensides on the fault surface, which rake only 25° northwest, suggest that the fault has a strike slip component greater than the dip slip.

COYOTE LAKE FAULT

The Coyote Lake fault in the Lane Mountain quadrangle was mapped by McCulloh (1953, p. 1512). He also determined the location of this fault under alluvium from a gravity survey of Coyote Lake basin. In the northwest part of Coyote Lake basin, the gravity data (McCulloh, oral communication, 1954) indicate a change in the strike of the fault from northeast to east.

The Coyote Lake fault enters the Alvord Mountain quadrangle from the Lane Mountain quadrangle at sec. 10, T. 12 N., R. 2 E., on the west, probably extends nearly due east largely under alluvium across the quadrangle, and may enter the Cave Mountain quadrangle on the east, where its further extension remains to be proved by detailed mapping. This major fault is indicated in the Alvord Mountain quadrangle by sheared, crushed basement rock in secs. 8 and 9, T. 12 N., R. 3 E. It may also extend eastward for an unknown distance under the alluvium as suggested by steep dips and minor faults in the granitic fanglomerate in secs. 8, 9, 10, 11, and 12, T. 12 N., R. 4 E. The granitic fanglomerate exposures also end along an apparent dissected scarp in these same sections. The easterly extension of the Coyote Lake fault possibly is exposed in a zone of crushed, sheared pre-Tertiary basement rock within granitic fanglomerate in sec. 12, T. 12 N., R. 4 E., near the east border of the quadrangle.

The presence of Coyote Lake basin on the south and McCulloh's gravity data (1953, p. 1512) indicate that in the western part of the quadrangle the relative movement is probably downward on the south side of the fault. The possible movement on the inferred extension of Coyote Lake fault or fault zone in the eastern half of its extent within the Alvord Mountain quadrangle is down on the north side, as indicated by the northward limit of the outcrops of granitic fanglomerate and also by the steep northerly dips in the granitic fanglomerate near the fault. The drag of beds against two minor subparallel faults in granitic fanglomerate near the east border of the quadrangle also suggests that the north side is down dropped. The apparent change of relative movement along the Coyote Lake fault is associated on the south side with the Alvord Mountain upwarp.

ALVORD MOUNTAIN UPWARP

The most conspicuous structural feature within the quadrangle is the upwarp centering at Alvord Mountain (pl. 1). The pre-Tertiary crystalline core in the central and western part of Alvord Mountain is flanked on the north, east, and southeast by Tertiary rocks. These rocks may flank the crystalline core on the west and southwest, but if they do, they are concealed by Recent alluvium and windblown sand. Viewed at a distance from the west the profile of the crystalline core in the western part of Alvord Mountain is seen to be that of a low asymmetric dome. The southern slope of the dome is somewhat steeper than the northern slope. In detail, however, little if any of this domed surface remains, but the tops of ridges and spurs gradually rise toward the central area, where the highest part and northern slope of the arched surface are preserved under the capping of Alvord Peak basalt. That the southern part of the range is in part the southern slope of an upwarp is indicated by southerly dips in the Alvord Peak basalt and by small patches of Barstow formation dipping southward around the mouths of Spanish Canyon and the canyon 1 mile to the west. Faulting has also played a part in the formation of the Alvord Mountain upwarp on the southern side, but just how much of the present height of the southern mountain front is due to upwarping and how much to faulting is difficult to assess. The above evidence suggests that warping of the range has predominated over uplift along marginal faults.

The east flank of Alvord Mountain consists of Tertiary and Quaternary rocks that in general lie around the crystalline core and dip away from it to form an eastward-plunging anticlinal arch, though the formations are deformed in detail by folds and many faults. The largest fold within this arch is the Spanish Canyon anticline (pl. 1), whose axis trends west of north, almost at a right angle to the direction of plunge of the arch. On the southeast this arch is broken by two major faults, one on each side of Clews Ridge. These faults may be branches of a southern boundary fault between Alvord Mountain and the basin to the south.

The Spanish Canyon anticline is a northward-plunging, somewhat asymmetric fold (pl. 1, section *B–B′*) that is complexly faulted. The beds on the western flank dip 20° to 30° northwest. The beds on the eastern flank dip more steeply northeast and east. The eastern flank is broken by minor high-angle, oblique-slip cross faults and several small southwest-dipping reverse strike faults, which cut out beds as seen in outcrop. In upper Spanish Canyon the western flank is broken by larger northeast-striking normal faults that dip 45° to 70° southeast (pl. 1) and repeat beds (pl. 1, section *A–A′*) as seen in outcrop. One of these northeast-trending faults extends across the axis of the Spanish Canyon anticline in the S½ sec. 29, T. 12 N., R. 4 E., between Spanish Canyon and the one to the east (pl. 6) and exposes the basement complex between these canyons. Near the nose of the Spanish Canyon anticline northeast-trending faults shift the anticlinal axis progressively westward; furthermore, the axis trends more westward as it passes into the granitic fanglomerate. On the east side of Spanish Canyon, in the SE¼ sec. 31, T. 12 N., R. 4 E., two small northwest-striking faults on the west flank bound a small graben, which exposes the Spanish Canyon formation within an area underlain by Alvord Peak basalt.

The Spanish Canyon anticline terminates on the south against a major northeast-trending fault between the mouth of Spanish Canyon and Clews Ridge. In lower Spanish Canyon the anticline is flanked on the west by an area of nearly flat-lying strata.

In the northern foothills of Alvord Mountain, axes of open folds in the granitic fanglomerate trend west-northwest to west. On the infacing bluffs on the northeastern flank of the Spanish Canyon anticline, beds of the Barstow formation dip 50° to 70° northeast. The basal beds of the granitic fanglomerate just above the unconformity dip 30° to 40° northeast, but the strike of the higher beds is slightly more westerly and dip is only 10° to 20° northeast. The many small cross faults on the northeastern flank of the Spanish Canyon anticline also disappear in the upper part of the granitic fanglomerate. The discordance in attitudes and the disappearance of faults within the basal part of the granitic fanglomerate indicate that folding and faulting of the Spanish Canyon anticline occurred prior to and during the deposition of the lower part of the fanglomerate.

South of the mouth of Spanish Canyon, attitudes in isolated outcrops of Barstow formation and granitic fanglomerate suggest a syncline although small outcrops of the underlying Alvord Peak basalt appear near the supposed axis. This anomalous relation may be due in part to a thinning of the Barstow at the edge of a basin and in part to topographic irregularity on the basalt; however, the syncline may be faulted by a southwest extension of the more southerly of the two faults to the northeast (pl. 1). It is also possible that these exposures of Alvord Peak basalt are interbedded with or intrude the Barstow formation.

Clews Ridge in the easternmost part of the Alvord Mountain upwarp is a tilted, gently southeastward-dipping block, which has been uplifted relative to the surrounding area by fault movement on three sides. The displacement on the irregular main break along the north side of Clews Ridge is large: The maximum displacement is approximately 1,000 feet in the SW¼ sec. 34, T. 12 N., R. 4 E., where the principal fault makes a sharp bend from east to north. East of this point the displacement is taken up by many faults. The fault mosaic north of Clews Ridge encloses a complex jumble of chaotically tilted beds of the Barstow formation that dip in every direction, though none of the dips exceed 30°. The same beds are repeated many times in the different blocks. The dry wash on the west side of Clews Ridge probably follows a fault, for beds of different lithology crop out along the strike at adjacent points on opposite sides of the wash (pl. 1).

The fault bounding the Clews Ridge block on the south is probably a branch of the main boundary fault on the south side of the Alvord

Mountain upwarp. Toward the east the fault extends into the Cave Mountain quadrangle, where it has a large displacement (A. M. Bassett, oral communication, 1954). Miocene beds south of Clews Ridge have a stratigraphic throw of 100 to 200 feet (pl. 1, section *A–A'*). The beds appear upthrown on the south side of this fault, but this apparent displacement may be due to left lateral strike-slip movement or relative eastward displacement of the south block. At the west end southwest of Clews Ridge this west-trending fault swings southwest.

STRUCTURAL PATTERNS IN ALVORD MOUNTAIN QUADRANGLE

The geologist is handicapped in synthesis of structural trends in the Alvord Mountain quadrangle by heterogeneity of rocks, extreme difficulty in correlating rock units between areas concealed by alluvium, and finally by the fact that structural movements have occurred at different times.

The tightly compressed folds with north-northwest- to northwest-trending axes in the pre-Tertiary (Precambrian?) metamorphic rocks in the northern part of the quadrangle and in Alvord Mountain are probably the result of a strong compressive stress normal to this trend. This stress may have been active before or during the invasion of the plutonic rocks. The granodiorite porphyry dikes filled parallel tensional fissures that opened N. 15°–25° W. some time after the plutonic rocks were emplaced in the folded metamorphic rocks and in apparent disregard of the planar structures of the metamorphic rocks. The pre-Tertiary rocks were thereby stabilized to a comparatively rigid mass prior to Tertiary time.

The structural pattern that evolved during the middle and later part of the Cenozoic era contrasts with that of the pre-Tertiary. East-trending faults, such as the Bicycle Lake, the Coyote Lake, and possibly the fault south of Clews Ridge, are high-angle breaks with a probable, but unproved, component of left-lateral strike-slip movement. Although they affect Quaternary fanglomerate they do not form high vertical scarps; on some faults vertical displacements are commonly reversed. The granitic fanglomerate is locally deformed into open folds with axes generally parallel to one of the major east-trending faults. These open folds probably resulted from compressive stresses related to movement along the faults. The same stresses may also have caused the folding of the Spanish Canyon anticline and later the upwarping of Alvord Mountain, for east-trending major faults probably form both the north and the south boundaries of the upwarp.

The major east-trending faults in the Alvord Mountain quadrangle parallel two similar large east-trending faults that extend across the

Tiefort Mountains quadrangle (fig. 1) just to the north (Hewett, 1954b, pl. 1). All these faults, including those in the Alvord Mountain quadrangle, are parallel to the east-trending Garlock fault (fig. 1), 25 miles north of the Alvord Mountain quadrangle. Northwesterly faults, parallel to the San Andreas fault and as nearby as the Opal Mountain and Daggett quadrangles (fig. 1), west and southwest, respectively, of the Alvord Mountain quadrangle, were mapped by Dibblee (1954) and by McCulloh (written communication, 1955). (See also Hewett, 1954b, pl. 1; Hill, 1954, fig. 1.) However, no faults of this system occur within the Alvord Mountain quadrangle. Thus it would seem that the rocks underlying the Alvord Mountain quadrangle have been influenced by tectonic forces that formed the Garlock fault, rather than by those that formed the northwest-trending San Andreas fault, which is twice as far from the quadrangle as the Garlock fault. The quadrangle is therefore probably near the south edge of the area influenced by movement on the Garlock fault.

GEOMORPHOLOGY

The landforms in the Alvord Mountain quadrangle of the central Mojave Desert evolved through the interplay of several factors, such as differences in lithology and structure, changes in climate (process), stage of the erosion cycle, and recency of structural events. The fact that structural movements may have occurred in relatively recent geologic time must always be considered in any discussion of landforms in southern California.

The uniformity of pebbles over a large area in the granitic fanglomerate and the overlying volcanic gravel indicate that the Alvord Mountain quadrangle had a more integrated drainage pattern during latest Tertiary and early Quaternary time than during late Quaternary. This drainage was in general from northwest to southeast. A remnant of an old surface, probably in part erosional and in part depositional, is preserved on the volcanic gravels over several square miles in the southeastern part of the Alvord Mountain quadrangle and in the western part of the adjoining Cave Mountain quadrangle. This surface is possibly the last remnant of the once integrated drainage and is possibly early to middle Pleistocene in age. Certain landmasses such as Alvord Mountain and the area of low hills carved in pre-Tertiary rocks in the northern part of the quadrangle almost certainly protruded during the period of integrated drainage, for detritus shed from Alvord Mountain appears in the boulders of the granitic fanglomerate southeast of Alvord Mountain.

Sometime during early or middle Pleistocene time, renewed movement along the major faults, as indicated by breccia and angular fan gravels, occurred along with more rapid uplift and upwarping of the positive areas, such as Alvord Mountain, and more rapid subsidence of previously existing Tertiary basins. This renewed movement resulted in dismembering the previously existing integrated drainage into the present small upwarps and basins such as the Langford Well Lake and Coyote Lake depressions.

Alvord Mountain is a maturely dissected asymmetric dome. The surface on pre-Tertiary rocks in the western part of Alvord Mountain is deeply incised by radial master canyons, especially in the southwestern part. This incisement is probably due to Pleistocene warping and uplift along a buried mountain-front fault along the southern edge of Alvord Mountain. The tributary gullies are subsequent, conforming to regional foliation and differences in lithology of the metamorphic rocks. The area underlain by Alvord Peak basalt in secs. 25, 26, 35, and 36, T. 12 N., R. 3 E., in the northern part of Alvord Mountain is but little dissected, owing to the resistance to erosion of the Alvord Peak basalt. The stage of the erosional cycle of that part of western Alvord Mountain underlain by pre-Tertiary crystalline rocks might be designated as early maturity, though this area has probably had a complex history dating from initial uplift sometime in the Miocene epoch.

The wash that drains westward along the north side of Alvord Mountain from sec. 25 to sec. 29, T. 12 N., R. 3 E., is mainly subsequent and is controlled by the contact between hard pre-Tertiary rocks and Alvord Peak basalt on the south and the less resistant Barstow formation and granitic fanglomerate on the north. This wash, however, has cut an elbow canyon or incised meander into the Alvord Peak basalt in the SE¼ sec. 22 and the NE¼ sec. 27, T. 12 N., R. 3 E. The gorge just east of the meander follows a narrow graben in which the Barstow formation was down-dropped in Alvord Peak basalt. Superposition best explains why the wash did not cut southwestward through the less resistant granitic fanglomerate: as the Alvord Mountain upwarp rose the wash eventually found itself astride the buried structural nose of Alvord Peak basalt that extends nearly a mile farther northward in secs. 22 and 23, T. 12 N., R. 3 E. The elbow or meander may have been caused by an initial diversion northward by the buried basalt, but the wash soon became incised into the basalt at its present position, which has a shorter distance and higher gradient than would exist if the wash were to maintain itself in granitic fanglomerate around the north end of the basalt nose.

The eastern part of Alvord Mountain is underlain by Tertiary rocks that are generally much less resistant to erosion than the pre-Tertiary rocks and Alvord Peak basalt in the western part of Alvord Mountain. Prior to the main upwarping of Alvord Mountain that began in Pliocene or early Pleistocene time, a wash in granitic fan gravel at the approximate site of Spanish Canyon probably followed a course around the east side of the pre-Tertiary crystalline core of western Alvord Mountain. As Alvord Mountain was elevated by warping and faulting during the late Pliocene or early Pleistocene, this wash probably maintained its antecedent position and cut a gorge through the Alvord Peak basalt. This wash was eventually cut off headward by resistant beds of granitic fanglomerate during the uplift of Alvord Mountain. The drainage south of the present mouth of Spanish Canyon was diverted southwestward by the barrier of fanglomerate and gravel hills southeast of Alvord Mountain in response to the uplift. Thus Spanish Canyon came into existence sometime during early or middle Pleistocene time. The relatively large area of watershed of upper Spanish Canyon was still sufficient, however, to maintain the basalt gorge in lower Spanish Canyon up to the present time.

The southward-draining washes, including those in the upper part of Spanish Canyon, generally follow the strike of the less resistant Tertiary beds. Headward erosion by these washes has shifted the Alvord Mountain divide northward into the tilted granitic fanglomerate, mainly because the base levels of Coyote Lake and of the Mojave River are several hundred feet lower than that of Langford Well Lake basin to the north.

The area underlain by metamorphic rocks north of Langford Well Lake has been deeply dissected by dry gulches that are in large part adjusted to the layering and foliation of the metamorphic rocks. This area has had some uplift along marginal faults during Quaternary time, but the subdued mature topography probably dates from some time in the late Tertiary.

A low dome, in the northwestern part of the quadrangle, carved on coarsely granular quartz monzonite, has been called the Noble Dome, after Levi F. Noble, by W. M. Davis (1933, p. 244; 1938, p. 1395–98). Though its gross surface is smooth, many large rounded bosses of quartz monzonite as much as 20 feet high protrude above its general surface. Actually this geomorphic feature is not truly a rounded dome but a very low asymmetric, elliptical cone, in part a pyramid, with its apex slightly rounded. The straightness of its outer slope and its localization on the coarsely granular quartz monzonite indicate that the dome evolved through coalescing of pediments through erosion rather than by unwarping. The steeper pediment slope on the southwest side toward the much lower base of Coyote Lake might be expected if the dome originated by erosion; however, a general southwestward tilting following pedimentation would also account for the asymmetry of the dome.

Physiographic depressions such as the Langford Well Lake and Coyote Lake basins probably began to assume their present form at the time of the destruction of the integrated drainage during early or middle Quaternary time. These basins probably formed in response to downwarping and subsidence related to movement on major faults. The best evidence in support of this hypothesis is that given by McCulloh (1953, p. 1512), who found by gravity measurements a large displacement on the Coyote Lake fault at the northwestern margin of Coyote Lake basin. Coyote Lake basin apparently formed as the depressed block on the southeast.

Shoreline features of Pleistocene Lake Manix are preserved principally around Coyote Lake basin. A relatively straight wave-cut bank in granitic fanglomerate, as much as 30 feet in height, extends N. 70° W. from the NW¼ sec. 25, T. 12 N., R. 2 E., to and beyond the edge of the quadrangle. The altitude of the base of this bank decreases from about 1,830 feet in the NW¼ sec. 25 to about 1,860 at the edge of the quadrangle (pl. 1), whereas the upper surface of the shoreline facies of the Manix lake beds is not more than a few feet above the 1,780-contour for a distance of about 3 miles southeast of Coyote Lake (pl. 1). The wave-cut bank north of Coyote Lake is dissected and slightly tilted, but so closely accords with the other elevations on the Lake Manix shoreline that the bank must have been cut during a stage of Lake Manix, possibly the early Wisconsin stage.

The playa surface of Coyote Lake is probably the remnant lake bottom of Pleistocene Lake Manix. This surface is nearly flat and is separated from the Mojave River depression to the south by a belt of Recent sand dunes that postdate Lake Manix. Actually a wash in the Lane Mountain quadrangle extends through the sand dune belt from the southwest corner of Coyote Lake south toward the Mojave River.

Small playas in linear arrangement extend southeastward from the SW¼ sec. 9, 3 miles east of Coyote Lake, to the NW¼ sec. 35, T. 11 N., R. 3 E. These playas all occur at the toe of the alluvial fan that slopes southwestward off Alvord Mountain. They appear to have been dammed on the west by the accumulation of windblown sand and silt at the east edge of the Coyote Lake depression.

GEOLOGIC HISTORY

The earliest recognizable geologic event in the Alvord Mountain quadrangle is the deposition of a thick sequence of sandstone, shaly sandstone, shale, and limestone now represented by quartzite, gneiss, schist, and crystalline limestone. These beds were probably deposited during Precambrian time. The thick, fairly continuous crystalline limestone suggests that these beds were deposited on the sea floor. Sometime during late Precambrian or possibly during early Paleozoic time, this ancient sequence was folded along north to northwesterly axes by compressive stresses normal to the fold axes. Possibly regional metamorphism and some emplacement of plutonic rocks occurred at this time.

The geologic record for most of the Paleozoic and Mesozoic eras is lacking in the Alvord Mountain and adjoining quadrangles. The presence in the surrounding region of thick limestone strata of late Paleozoic age indicates that the late Paleozoic seas also probably once covered the Alvord Mountain quadrangle, for the Paleozoic seas in which these rocks were deposited were fairly extensive. The area may have been submerged under the sea during Triassic time as suggested by the occurrence in the Lane Mountain quadrangle of marine sediments of doubtful Triassic age. During late Mesozoic time, after withdrawal of the Paleozoic and Triassic(?) seas, the area underwent regional diastrophism which involved folding of the sedimentary sequence and intrusion by plutonic rocks.

During late Cretaceous or early Tertiary time granodiorite porphyry was intruded along north-trending fractures in the metamorphic and plutonic rocks of the Alvord Mountain area. The rhyolite dikes may also have been intruded at this time or later in the Tertiary period. The deposition of the arkosic conglomerate may have occurred during this time interval or it may antedate the plutonic rocks.

During the early part of the Tertiary period the area of the Alvord Mountain quadrangle and most of the Mojave block was undergoing uplift and erosion. This early Tertiary landmass was defined by Reed (1933, p. 17) as "Mohavia." Drainage was external and probably well integrated. Within the quadrangle the only geologic record of this period of deep erosion is the fact that Tertiary beds rest on a deeply eroded basement of metamorphic and plutonic rocks. The climate was probably more humid than at present and a reddish lateritic soil formed on the bedrock. This erosional surface still maintained some topographic relief, however, at the end of the long erosional interval, as shown by the uneven contact at the base of the Clews fanglomerate, the oldest Tertiary formation.

Local basins came into existence probably as the result of movement on major faults sometime during early or early middle Miocene, and fine-grained sediments and limestone that form the basal part of the Clews fanglomerate were deposited in a lake of an enclosed basin. Falls of fine volcanic ash were included with the sediments. Continued movement by faulting or warping brought local areas of the Alvord Mountain quadrangle under erosional attack, and the fanglomerate beds of the Clews fanglomerate were deposited. The reddish-brown matrix of the fanglomerate is probably reddish soil that was stripped from the areas undergoing erosion. As the local basins became filled with debris a few stream washes extended northwestward beyond Alvord Mountain and tapped areas of light-colored quartz monzonite. At about this same time, volcanic ash falls, possibly derived from volcanism to the west, were deposited with the uppermost beds of the Clews fanglomerate.

Many of the events of middle(?) Miocene volcanism are recorded at Alvord Mountain after the deposition of the Clews fanglomerate. The Alvord Peak basalt was extruded from local vents, some of which were on or near the axis of the ancestral Spanish Canyon anticline. Several flows aggregating a thickness of at least 400 feet were poured out both on crystalline basement rock and on the Clews fanglomerate where its upper surface was flat, as on the west flank of the Spanish Canyon anticline. Where the upper part of the Clews fanglomerate was coarse and probably higher on alluvial slopes, the basalt is absent. Possibly the folding of the ancestral Spanish Canyon anticline had already begun; if so, this folding may have limited the extent of the Alvord Peak basalt to the area west of the axis.

A short period of erosion may have followed the extrusion of the Alvord Peak basalt, or the surface of the basalt may have had initial irregularity. Ash falls and reworked ash, now white tuff at the base of the Spanish Canyon formation, accumulated in valleys on the Alvord Peak basalt and on the Clews fanglomerate. Coarse clastic beds of the Spanish Canyon formation were derived both from local bedrock sources and from sources external to Alvord Mountain. Two fluid olivine basalt flows, separated by deposits of clastic material, spread out on broad washes through the site of the eastern part of Alvord Mountain and were probably derived from source vents to the northwest.

By late(?) middle Miocene time, a basin, whose upper end occupied the site of eastern Alvord Mountain, began to subside more rapidly than during the earlier part of the Miocene; several hundred feet of arkosic sandstone and conglomerate of the Barstow formation were deposited. The source of the blocks of banded argillite lay in the Paradise Range to the northwest. The more rapidly subsiding part of the basin probably lay to the southeast, for the lower member of the Barstow formation thickens and becomes finer grained in that direction—opposite from the inferred source area. Herds of the primitive small middle Miocene horse, *Merychippus tehachapiensis*, were plentiful. In latest middle Miocene time, after deposition of the lower member of the Barstow formation, volcanic eruptions occurred northwest or west of Alvord Mountain and deposited several thin layers of granular pumiceous ash with the clastic beds. Horses, camels, and other ungulate mammals were probably killed and subsequently preserved by the ash falls. Shortly after the ash falls, a basalt flow was extruded from a vent in the northwestern part of Alvord Mountain. In the eastern part of the Alvord Mountain area and perhaps in the northwestern part, volcanic gravels and arkosic sands were deposited on the tuffaceous member. If they were deposited in the northwestern part, they were soon eroded away. The highlands mass of Alvord Peak basalt and possibly pre-Tertiary rocks of the crystalline core of Alvord Mountain were almost buried by the end of late Miocene time.

In early Pliocene or possibly latest Miocene time, granitic fanglomerate was deposited conformably on the Barstow formation in a local basin in the north central part of Alvord Mountain, while adjacent parts of the upper member of the Barstow formation were undergoing erosion. Folding of the Spanish Canyon anticline began at the same time and continued during the deposition of most of the fanglomerate. The granitic fanglomerate was derived largely from light-colored quartz monzonite exposed in the northwestern part of the quadrangle and beyond. By late Pliocene or early Pleistocene time, however, the anticline and most of Alvord Mountain were probably nearly buried by granitic fanglomerate.

In late Pliocene or early Pleistocene time explosive volcanism in the Lane Mountain quadrangle extruded vast quantities of rhyolitic tuff-breccia, tuff, andesite, latite, and dacite flows into the northwestern part of the Alvord Mountain quadrangle. Olivine basalt was extruded over the pile of silicic volcanic rocks. Erosion of this great volcanic field brought large quantities of volcanic gravel to the south, southeast, and south and nearly covered the present site of the Alvord Mountain.

In Quaternary time, probably while the volcanic gravels were still accumulating in the eastern part of the Alvord Mountain quadrangle, renewed movement took place on the major faults, and breccias accumulated downslope from the intersection of the faults with the surface. During this time a strong recurrent movement in the Alvord Mountain area formed the Alvord Mountain upwarp, which was a result in part of uplift on the southern boundary fault and in part of arching that involved the overlying Tertiary rocks as well as the basement rocks. After deposition of the volcanic gravel, there was recurrent arching of the Alvord Mountain upwarp and activity on most of the mapped faults, as indicated by the unconformity at the base of this gravel. The present topography is the result of this movement, which was the local effect of the widespread early to middle Pleistocene diastrophism. Spanish Canyon and adjacent washes to the east maintained courses in softer rocks wherever possible during the upwarping of Alvord Mountain. The integrated drainage system that had been maintained across the Alvord Mountain quadrangle through much of late Tertiary time was interrupted and small local basins, such as Langford Well Lake basin, began to take shape.

Probably also during early or middle Quaternary time, continued movement on the Bicycle Lake fault zone in the northern part of the quadrangle tapped basalt magma in the deeper layers of the earth's crust. Basalt welled up along the southernmost fissure of the fault zone and flowed northward into the valley south of the Tiefort Mountains. Landslide and talus composed largely of basalt, including Tertiary basalts, accumulated near basalt cliffs that were underlain by less resistant rocks.

In late Pleistocene (Wisconsin) time much of Coyote Lake basin was inundated by Lake Manix during the period of excessive rainfall that probably coincided with continental glaciation to the north. Beds of fine silt and sand were deposited in the Coyote Lake embayment and in the part of the lake south of the Alvord Mountain quadrangle. Sand beach ridges and gravel bars were laid down as shoreline deposits. The present alluvial terraces were deposited in washes tributary to the lake.

Recent geologic events, since the drying up of Pleistocene Lake Manix, include deposition and erosion of the older windblown sand and deposition of alluvium, windblown sand, and clay and silt of the present playa lakes.

ECONOMIC GEOLOGY

The only deposits of economic significance in the Alvord Mountain quadrangle are gold, tungsten, and two limestone deposits. Gold has been produced intermittently since 1885 from the Alvord mine lode on the southern side of Alvord Mountain. A group of tungsten claims was located in May 1953 on tactite and limestone on the northwestern side of Alvord Mountain. The two limestone deposits (pl. 1), one in a group of claims at the Alvord mine and the other in the low hills northeast of Langford Well Lake, aggregate millions of tons. Two previously unknown, though minor, occurrences of borate minerals were found during the period of fieldwork, but no saline deposits of economic significance are known within the Alvord Mountain quadrangle. The famous Calico borate deposits, however, are in the lower part of the Barstow formation several miles west-southwest of the southwest corner of the quadrangle, and similar borate deposits may exist in the Barstow formation just outside the borders of the quadrangle.

GOLD DEPOSITS

ALVORD MINE

The gold lode at the Alvord mine on the southern side of Alvord Mountain (pl. 1) was discovered in 1885. During the period 1885 to 1891, the property was operated by the Carter Gold Mining Co., and the ore was treated in a five-stamp mill at Camp Cady on the Mojave River. This operation produced an estimated total of $50,000 in gold (Storms, 1893, p. 360). From 1906 to 1910, the Alvord Gold Mining Co. operated the mine and installed the present 6-stamp mill (Tucker and Sampson, 1943, p. 439). The property was also operated from 1916 to 1920 by the Tintic Bonzana Mining property. In 1925, the Dell'Osso Gold Mining Co. acquired the property, and six claims were patended in 1931. According to Mr. F. G. Dell'Osso, president of the company, the property was active for several months during 1932 and 1933 and was under lease to Roy Waughtel from December 1950 to January 1952. Since January 1952 to the time of present writing (January 1955) the property has been idle.

The mill that was built in 1906 was used to treat the ore during the operation from 1950 to 1952. The gold ore was crushed by 6 stamps weighing 1,800 pounds each, and each stamp crushed about 5 tons of ore per day. The gold is free milling and prior to 1950 was recovered on 6 amalgam plates and by cyanidation. Recovery was 90 to 96 percent. The milling procedure was altered in 1950 by Roy Waughtel in order to increase recovery. The ore was first crushed, and then the coarse gold was recovered by jigging and the finer particles by amalgamation. The pulp was further treated by classifier and ball mill, and the gold was recovered from the finely ground pulp by flotation. The gold-bearing amalgam was sent to the U.S. Mint at San Francisco, and the flotation concentrates were sent to the smelter at Garfield, Utah, for further treatment. The mill, like the mine, has been idle since January 1952, when the Waughtel lease was terminated.

The gold lode is a fissure vein entirely in metalimestone and is largely replacement of limestone parallel to the bedding. The vein strikes N. 70° W. and dips 70° S. at the portal of the lower tunnel. The vein is approximately in the center of the limestone layer, and if the deduction that the limestone is an isoclinal fold is correct (see p. 48), the vein occupies the axial plane of the fold. Eastward the strike of the vein, like that of the limestone, becomes more easterly. The principal workings on the vein include a lower tunnel, which extends 440 feet eastward, and an upper tunnel, about 100 feet above the lower and extending 360 feet east to the face. These tunnels are actually in the hanging-wall limestone; short crosscuts extend several feet north to the stopes on the vein. A quarry, called the Crows Nest, is 50 feet above the upper tunnel, and southeast of the Crows Nest a glory hole extends about 75 feet from the upper level to the surface. Two large stopes, one of which was made during the Waughtel operation from 1950 to 1952, extend from the lower to the upper level. Two crosscuts into the hanging-wall limestone penetrate a granodiorite porphyry intrusive mass, which is not exposed on the surface.

In the glory hole the vein is as much as 10 feet wide near the surface but is 1 to 5 feet wide in most places where seen in the mine. At the surface, the vein consists of hard jasper, which is stained light to moderate brown, moderate to dusky red, and grayish black by limonite, hematite, and sparse manganese oxides, respectively. Blebs of clear quartz and sparse and drusy veinlets of clear quartz cut the jasper. At the lower level, quartz and jasper are less abundant and the vein is largely an ocherous-yellow and reddish-brown aggregate of limonite and hematite. In places, blue-green chrysocolla veinlets occur on the walls of the vein. The radioactivity of the chrysocolla veinlets is several times background count as recorded by Geiger counter.

None of the original unoxidized vein minerals of the protore were seen in the mine by the writer, but iron sulfides have been reported (Tucker and Sampson, 1943, p. 439). It is inferred that prior to oxidation the vein originally consisted largely of pyrite, calcite, and quartz, with sparse amounts of arsenopyrite, galena, and chalcopyrite.

OTHER GOLD PROSPECTS

A few short adits and prospect pits have been dug along or near the granodiorite-schist contact in sec. 28 in the northwestern part of Alvord Mountain, apparently in search of gold ore. No minerals other than quartz of the vein-stringer type were observed in any of these workings. They have probably been idle for many years, and the current ownership is not known.

TUNGSTEN DEPOSITS

The tungsten mineral, scheelite, was observed in a few tactite bodies on the northwestern side of Alvord Mountain, and doubtless occurs elsewhere. The tactite body in which the main concentration of scheelite was observed is entirely within granodiorite about 150 yards from the contact with schist. Tactite masses associated with crystalline limestone near the Alvord mine are chiefly garnet (andradite, n=1.87), and those masses examined were barren of scheelite. Further prospecting, however, seems warranted before the possibility of scheelite in the area of the Alvord mine can be eliminated. The contact between intrusive rock and metamorphic rock (pl. 1) should be prospected on both sides for 200 yards, because some scheelite-bearing tactite remnants of sufficient size to constitute a small ore body may occur in either the intrusive rock (diorite or granodiorite) or the metamorphic rock. These bodies would probably not appear conspicuous either on air photographs or on the ground, especially if the bodies are within the dark biotite schist.

STARFIRE GROUP

The Starfire group of tungsten claims was located on May 13, 1953, by George Cleminson, D. M. Clark, Kenneth Wilhelms, and William Keon, in the NE¼ sec. 33 and the SE¼ sec. 28 T. 12 N., R. 3 E., (pl. 1). Clark and Wilhelms were residents of Manix in 1954.

The limestone mass in the NE¼ sec. 33 dips 80° W. and is about 500 feet thick. The limestone contains bodies of tactite. Along the strike the limestone appears to grade into tactite and schist, but the relations have not been studied in detail. A quarry pit 15 feet high and 20 feet long has been blasted in the west side of the crystalline limestone body, and several other smaller pits have been dug in the limestone just above the east end of the quarry. Both the quarry and the pits contain anastomosing veinlets of quartz and wollastonite in gray coarsely crystalline limestone. Rare grains of scheelite were observed in the wollastonite. A garnet tactite body covering 20 by 100 feet of outcrop area occurs within the limestone 200 feet north of the quarry and consists largely of garnet (almandite(?), n=1.78) and calcite, with rare grains of scheelite. Small tactite bodies on the east (footwall) side of the limestone mass contain quartz, wollastonite, and almandite(?) (n=1.81). The tactite bodies along the footwall of the limestone are separated from schist by apophyses of granodiorite pegmatite. Scheelite was not observed in these bodies but may well be present.

Scheelite-bearing tactite is exposed in granodiorite in the bottom of a 15-foot trench about 200 yards from the granodiorite-schist contact in the SE¼SE¼ sec. 28. The tactite band is 4 feet thick and is entirely with granodiorite. The band where exposed in the bottom of the trench strikes N. 55° W. and dips 70° SW. The band is cut by stringers of granite (quartz-feldspar-biotite) pegmatite, which merge toward the west into a dike of graphic granite, striking N. 70° W. and dipping 80° S. The tactite consists of quartz, green hornblende, a white cloudy claylike aggregate, calcite, limonite, and abundant granular scheelite. Scheelite was confirmed microscopically by Robert D. Allen. A grab sample from several ore sacks at the pit also contains scheelite, garnet (almandite-andradite, n=1.85), green hornblende, quartz, epidote, and diopside(?). A spectrochemical analysis of this grab sample is given in table 4. This sample is significant qualitatively, but should not be regarded as quantitatively representative of the ore.

TABLE 4.—*Spectrochemical analysis of grab sample of scheelite-bearing tactite from Starfire group of claims, SE¼SE¼ sec. 28, T. 12 N., R. 3 E.*

[Analysis by Pacific Spectrochemical Laboratory, Hal W. Johnson, director]

Element	*Percent*	*Element*	*Percent*
Sodium	1.0	Copper	0.01
Tungsten	.70	Zirconium	.01
Manganese	.3	Gallium	.005
Titanium	.2	Nickel	.003
Calcium	.2	Cobalt	.002
Molybdenum	.06	Boron	.002
Strontium	.03	Chromium	.001
Vanadium	.02		

LIMESTONE DEPOSITS

DELL'OSSO GROUP

The mass of metalimestone that crops out in southwestern Alvord Mountain is held by the Dell'Osso Gold Mining Co. According to Mr. Dell'Osso, the limestone is included in the 6 patented claims of the Alvord gold mine and 11 additional claims held by location. This limestone is a potential source of lime for cement manufacture.

OTHER LIMESTONE DEPOSITS

The metalimestone bed in the northern part of the quadrangle crops out principally in secs. 8 and 16, T. 13 N., R. 4 E. This bed appears to be of high purity, but its location within the boundaries of the Camp Irwin Military Reservation and its great distance from potential markets are likely to prevent commercial development for many years.

OCCURRENCE OF SALINE MINERALS

Two deposits of borate minerals on the edges of the Alvord Mountain quadrangle are associated with tuffaceous or bentonitic sediments, opaline chert, and limestone. Colemanite(?) and howlite in sparse amounts occur in a bentonitic shale bed just below bedded opaline chert and limestone in the tuffaceous sediments of the volcanic beds in the northwest corner of the quadrangle (see stratigraphic section, p. 41). At the southern border of the quadrangle in sec. 31, T. 11 N., R. 3 E., a bentonitic silty tuff interbedded in the volcanic gravel contains howlite and colemanite in trace amounts associated with clay, calcite, gypsum, and celestite (minerals identified by Robert D. Allen). This bed is 1 foot thick and is olive gray to dark greenish gray. Altered tuff (clay) and gypsum, which occurs in several ½-inch cross-fiber veinlets parallel to the bedding are the dominant constituents. It is perhaps worthy of note that both these occurrences of borate minerals are associated with volcanic ash beds, one of which is overlain by opaline chert and limestone.

Economically significant deposits of saline minerals probably do not occur within the borders of the Alvord Mountain quadrangle but may occur some distance beyond the borders to the east and south. In the geology section of this report (p. 33 to 35) it was pointed out that the source of the pebbles in the Barstow formation and overlying gravels was from the northwest. The sediments in the lower member of the Barstow formation, in which Tertiary borate deposits are most likely to occur, also thicken and become finer grained toward the southeast. Hence, any borates or other salines must have moved across the quadrangle from northwest to east, southeast, or south. More information on the accumulation of saline deposits in Tertiary basins beyond the borders of the quadrangle could be obtained by additional geologic mapping in quadrangles to the east and south, by geophysical and geochemical surveys, and ultimately by drilling.

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INDEX